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Solar Industrial Process Heat Systems -- An Assessment of Standards for Materials and Components

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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Prepared for

Solar Thermal Technology Division
Office of Solar Heat Technologies
Conservation and Renewable Energy
U.S. Department of Energy
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SOLAR INDUSTRIAL PROCESS HEAT SYSTEMS -- AN ASSESSMENT OF STANDARDS FOR MATERIALS AND COMPONENTS

Walter J. Rossiter, Jr.
Walter E. Shipp

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

A study was conducted to obtain information on the performance of materials and components in operational solar industrial process heat (IPH) systems, and to provide recommendations for the development of standards including evaluative test procedures for materials and components. An assessment of the needs for standards for evaluating the long-term performance of materials and components for IPH systems was made. The assessment was based on the availability of existing standards, and information obtained from a field survey of operational systems, the literature, and discussions with individuals in the industry. Field inspections of 10 operational IPH systems were performed. The study did not address the thermal efficiencies and health and safety considerations of IPH systems.

The results of the study are presented in this report. It is concluded that standard test methods are needed for evaluating the long-term performance of materials and components used in IPH systems operating at high temperatures. Some standard test methods are available having applicability to materials and components in low temperature systems. However, in the latter case, data bases are lacking which demonstrate their applicability. Recommendations are made and priorities assigned for the development of standards for materials and components.

Keywords: field survey; industrial process heat; materials performance; solar collector; standards; test methods.

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1. INTRODUCTION

1.1 BACKGROUND

The use of solar energy in industrial process heat (IPH) applications offers tremendous potential for a reduction in fossil fuel energy consumption. Industry accounts for about forty percent of the total energy consumed in the United States, most of which is derived from fossil fuels [1].* Fifty to seventy percent of this industrial energy consumption may be used as heat for industrial processes [2]. Industrial process heat has been defined as thermal energy used in the preparation and treatment of goods produced by manufacturing processes. Twenty-seven percent of industrial process heat has a temperature below 288°C (550°F). Supplying this twenty-seven percent of industrial process heat as solar energy is attractive, since solar technology including concentrating collectors is available to collect heat below this temperature. Moreover, the use of solar energy is currently most cost-effective below 288°C (550°F)[2]. In addition, it has been estimated that, if solar preheating to 288°C (550°F) is used in processes which require higher temperatures, approximately 51 percent of industrial process heat may be supplied with available solar equipment [2].

1.2 THE SOLAR INDUSTRIAL PROCESS HEAT PROGRAM

The U.S. Department of Energy (DoE) has established the solar industrial process heat (IPH) program [3]. The IPH program provides direction, funding, and management of solar projects applying the direct conversion of solar energy to useful thermal energy for industrial process heat systems. The program objectives are to stimulate and demonstrate the use of solar technologies as a replacement for and supplement to fossil fuels presently used for industrial processes. The program which focuses on experimental and field test projects provides the means for industry to perform government-funded experiments and to construct cost-shared prototype solar systems. Specifically, the IPH program has been designed to:

- assess industrial processes where solar energy may supply a significant amount of process heat;
- design solar systems which can supply significant amounts of process heat;
- experiment with various designs to determine the best method of deriving industrial process heat; and
- demonstrate by the installation of large scale cost-shared systems, the capacity of solar energy to provide significant amounts of the process heat requirements of various industries [3].

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* Numbers in brackets indicate references listed in section 7.

Solar energy applications for industrial processes were originally categorized into three [3] depending upon the temperature of the process:

- low temperature applications, below 100°C (212°F);

- intermediate temperature applications, ranging from 100 to 177°C (212 to 350°F); and

- high temperature applications, above 177 to 288°C (350 to 550°F).

Thirteen field test projects with prototype operational solar systems are included in the IPH program* and are divided in four cycles [4]. Projects in the first three cycles (I-III) are designed to supply process heat within three ranges: hot water, low temperature steam, and intermediate temperature steam. The collector arrays for projects in Cycles I-III have collector areas about 929 m^2 (10,000 ft^2) or less in size. Cycle IV projects include processes which require heat over the range of low to high temperature applications and have collector arrays which may be as large as 4645 m^2 (50,000 ft^2).

The low temperature applications in Cycle I provide for industrial hot water up to 100°C (212°F). Industrial processes in Cycle I include hot water for can washing, concrete block curing, and textile dyeing. Cycle II field test projects provide low temperature steam up to about 177°C (350°F) in processes involving gauze bleaching, pasteurization, laundering, and textile drying. Intermediate temperature steam in the range of 149 to 288°C (300 to 550°F) will be supplied by Cycle III projects. The industrial processes for Cycle III projects are latex production, beer brewing, oil refining, and potato processing. The two Cycle IV processes will provide hot water for the washing of machined parts and steam for polystyrene production.

Three types of collectors, flat-plate, evacuated-tube, and line-focus, may be used for generating solar industrial process heat [3]. The type of collector may be selected depending upon the temperature range of the IPH application. Table 1 shows the temperature range at which each type of collector normally operates. As may be seen in table 1, the operating temperature ranges of the three collector types overlap one with another. Line-focus collectors are used for the higher temperature processes.

The success of the IPH program is dependent in part on the reliability of the system materials and components to perform satisfactorily over the long-term. Standards including test methods to evaluate materials are generally not available to assist architects, engineers, and other designers in the selection and procurement of materials for use in solar IPH systems. Since these standards could help assure the design and construction of systems which would reliably perform, and contribute to the commercialization of the solar IPH industry,

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* When the solar process heat program was initiated, it encompassed agricultural as well as industrial processes. These two programs are now separated with thirteen projects classified as industrial [4].

Table 1. Types of Collectors for Solar Industrial Process Heat Systems and the Operating Temperature Ranges

Type of Collector	Operating Temperature Range °C	°F
Flat-Plate	27 - 93	80 - 200
Evacuated-Tube	49 - 177	120 - 350
Line-Focus	66 - 288	150 - 550

the Department of Energy (DoE) requested the National Bureau of Standards (NBS) to evaluate the need for materials standards for solar IPH systems. It is essential to assess materials performance in operational IPH systems in order to identify the needs for standards and to obtain information to aid in the development of the standards.

A study was conducted in 1977 at the National Bureau of Standards (NBS) to evaluate the performance of materials in solar systems primarily intended for the supply of space heating, cooling, and hot water [5]. A major conclusion reached in the study was that "the process of selecting materials for specific applications within solar energy systems is hindered by the lack of an adequate data base of materials performance under the conditions experienced in solar systems and subsystems." The report [5] gave impetus to the initiation of a number of projects by NBS to assist in developing the technical bases for standards for materials used in residential and commercial solar systems for the supply of building heating, cooling, and hot water. For the most part, these materials standards were developed for flat-plate collectors. Industrial process heat systems use primarily evacuated-tubes and line-focus collectors and to a lesser extent, flat-plate collectors. The former types of collectors may subject materials to conditions not commonly experienced by flat-plate collectors in residential and commercial systems. In particular, operational parameters such as temperatures, pressures, and liquid flow rates may be higher. IPH systems may also be located in industrial areas where the environment including atmospheric contaminants may be harsh. In addition, the IPH systems may be larger and more complex than residential and commercial systems. For these reasons, the existing material standards for solar components may not be applicable to IPH systems. Existing standards may need to be modified or new standards developed.

1.3 OBJECTIVES

This report presents the results of the DoE-sponsored study to evaluate the need for materials and component standards for solar IPH systems. The objectives of the study were: to obtain information on the performance of materials and components in operational solar IPH systems, and to provide recommendations

for the development of standards including test methods for the evaluation of materials and components used in these solar systems.

1.4 SCOPE

Data and information presented in this report were obtained from a field survey and the published literature. Ten solar installations were inspected during the field survey. Eight of these systems were field test projects in the DoE industrial process heat program. Two of the installations were agricultural. These latter two installations were inspected, since the solar systems were of the type used for IPH applications.

The project plan addressed only the performance of materials and components in IPH systems. An assessment of the thermal efficiencies and health and safety considerations of the operational solar systems to provide industrial process heat was beyond the project scope. Information from the literature and field survey was complemented by that obtained in discussions with individuals knowledgeable in the field including architects, engineers, and solar system manufacturers.

2. FIELD OBSERVATIONS OF MATERIALS PERFORMANCE

The field inspections were intended to provide observations of materials and components performance for operational systems. The ten solar IPH systems inspected during the field phase of the study are listed in table 2. The location of the installation, the type of industrial process, the type of collector system, the size of collector arrays, operating temperatures and pressures, system energy output, and the operational status of the system at the time of the visit are also given in table 2. Appendix A presents a summary description of each system visited.

All installations were DoE-sponsored field test projects. The three types of collectors currently in use for IPH applications, flat-plate, evacuated-tube, and line-focus (parabolic trough and fixed receiver/tracking mirror), were included in the inspections. Six of the ten systems were operational at the time of the inspection. Two other systems were constructed but not operating when visited because of failures in key components. The remaining two sites were under construction which was close to completion. Each of these latter systems had collected some energy, as the collectors were being checked out in preparation for becoming operational. The maximum age of the operational systems was about 2 1/2 years which was considered a relatively short time to assess materials performance in service. The systems were located in various sections of the United States having different climates. A summary of the status of all IPH projects including those visited has recently been published [6].

As determined based on discussions with site personnel and observations made during the field survey, a wide variability in the performance of the various IPH installations existed. It is emphasized that this judgment is qualitative, since measurements relating to system performance were not conducted and were beyond the scope of the study. On one extreme, at one site personnel indicated that the operation of the system was successful to the extent that they were considering an increase in the size of the solar system. On the other extreme, as mentioned above, two systems were nonoperational because of materials failures. The other sites visited were performing between these extremes. Some sites had experienced few problems and had operated satisfactorily since their construction. In one case, the solar system had experienced periods of inoperation due to leaks in the heat transfer fluid circulating system.

Problems of varying degrees were observed at all the sites. Some problems concerned unsatisfactory materials performance, while others centered on inadequate design. The emphasis in this section is to report observations concerning unsatisfactory materials performance; however, reference is made to materials and components which were functioning satisfactorily. Discussions with site personnel indicated that in some cases, components had performed inadequately and been replaced before the field visits. Reference is made to these replacements in the report.

The observations on materials problems are given for the various components of the different types of collector systems. These components, given in alphabetical sequence, include: absorptive coatings, absorber plates, containment

Table 2. Solar Industrial Process Heat Systems Inspected During the Study[a]

Site No.	Location	Process	Collectors	Array Size m^2 (ft^2)	Collection Temp. or Steam Conditions	Designed Annual Energy Delivery $kJ/m^2/yr$ ($1,000\ Btu/ft^2/yr$)	Status at the Time of Visit
			LOW TEMPERATURE HOT WATER/HOT AIR				
Hot Water							
1	Sacramento, CA	can washing	flat-plate (liquid) and parabolic trough	681 (7,335)	66°C (150°F)	341 (300)	operational (June 1978)
2	LaFrance, SC	textile dyeing	evacuated-tube	621 (6,680)	132°C (270°F)	238 (210)	operational (Oct. 1978)
3	Harrisburg, PA	concrete block curing	fixed-receiver/ tracking mirror	856 (9,216)	57°C (135°F)	185 (163)	operational (Sept. 1978)
Hot Air							
4	Gilroy, CA	onion drying	evacuated-tube	553 (5,950)	99°C (210°F)	446 (393)	operational (Sept. 1978)
5	Fresno, CA	fruit drying	flat-plate (air)	1,951 (21,000)	63°C (145°F)	125 (110)	operational (Aug. 1978)
			LOW TEMPERATURE STEAM				
6	Pasadena, CA	commercial laundering	parabolic trough	603 (6,496)	171°C (340°F) 0.86 MPa (125 $lb/in.^2$)	283 (249)	under construction
7	Sherman, TX	gauze bleaching	parabolic trough	1,070 (11,520)	174°C (345°F) 0.86 MPa (125 $lb/in.^2$)	139 (122)	operational (Jan. 1980)
8	Bradenton, FL	orange juice pasteurizing	evacuated-tube	929 (10,000)	177°C (350°F) 1.03 MPa (150 $lb/in.^2$)	307 (270)	non-operational
9	Fairfax, AL	fabric drying	parabolic trough	772 (8,313)	158°C (317°F) 0.59 MPa (85 $lb/in.^2$)	150 (132)	non-operational
			INTERMEDIATE TEMPERATURE STEAM				
10	Dalton, GA	latex production	parabolic trough	923 (9,930)	186°C (367°F) 1.14 MPa (165 $lb/in.^2$)	286 (252)	under construction

(a) System descriptions from reference [7]

materials, covers/jackets, drive systems, evacuated tubes, flex hoses/swivel joints, fluids, insulation (thermal), pumps, receiver tubes, reflective surfaces, seals, trackers, and troughs (parabolic). The following subsections present a summary of the observations for each component and make reference to selected photographs from the field inspections. The photographs may be found at the end of this section.

2.1 ABSORPTIVE MATERIALS

- In one flat-plate system, the black velvet, nonselective absorptive coating was peeling from a number of the aluminum absorber plates. A representative of a collector manufacturer indicated that the poor adhesion of the coating may have been due to improper cleaning and preparation of the aluminum surface combined with the use of a brittle coating. Moisture had penetrated into some of the collector enclosures. Condensation was present on the underside of some of the cover plates when observed during mid-morning (figure 2.1). It was not determined whether there was a relationship between the peeling of the coating and the moisture.

- Black chrome selective coatings were used on the receivers of the six line-focus systems. For two installations, a black non-selective coating had been field applied to the receiver tubes reportedly because of degradation of the original black chrome. At one of these installations, some sections of the receiver tubes had the absorptive coating directly exposed to the weather, since glass jackets were missing (figure 2.2). The piping was copper. In another case, deterioration of the selective coating was observed, even though the system was not fully operational. In this case, the receiver tube piping was specified as being stainless steel. Low heat transfer fluid flow rates through the receiver tubes during system check-out reportedly resulted in excessive heating of the receivers, exposing the selective coating to temperatures in excess of the design limits. At another installation the black chrome coating appeared in good condition, except that some small sections of the receiver tubes had some spotting and white deposits (figure 2.3). The receiver tube piping was specified as carbon steel.

2.2 ABSORBER PANELS

- White deposits were observed on the upper surfaces of some absorber panels at the only liquid system inspected having flat-plate collectors. In this case, the absorber panels, which contained a black velvet, non-selective coating, consisted of copper tubing sandwiched between two formed aluminum plates attached with pop rivets. The heads of many rivets visible through the cover plates had white deposits on them (figures 2.1 and 2.4). Moisture was condensed on the underside of the cover plates of many collectors where the white deposits were observed on the absorper panels. It was not determined whether the formation of the white deposits was related to the presence of the moisture.

- For the one air system inspected, the absorber ducts generally appeared to be in good condition, although a few small sections contained white deposits

(figure 2.5). The absorber ducts consisted of galvanized steel with a black velvet, non-selective coating.

2.3 CONTAINMENT MATERIALS

- A containment material is one which encloses the heat transfer fluid or is in contact with the heat transfer fluid or storage material or both. Containment materials, as discussed here, primarily concern piping and storage systems. Specific containment components such as flex hoses, swivel joints and pumps are discussed in other sections of the report (sections 2.7 and 2.10). Piping for the six line-focus systems inspected consisted of steel, stainless steel, or copper. For the three evacuated-tube systems two had copper tubing and one had stainless steel tubing within the glass shrouds.

- Observations concerning the external appearance of containment materials indicated few problems. Observations were not made concerning the internal appearance of the containment materials, since the systems were generally operational and taking test cuts was beyond the project scope. Corrosion was observed on some brass elbow fittings connecting copper receiver tubes and copper flex hoses at one line-focus installation (figure 2.6). Some of the corroded elbow fittings were leaking. A representative for the collector manufacturer indicated that the corrosion may have been due to galvanic corrosion in addition to inadequate selection of the alloy composition. The fluid in the system was filtered well water. The corroded elbows were connected to the top of the flex hoses. Similar elbow fittings at the bottom of the flex hoses were not leaking.

- Leaks in the heat transfer fluid piping systems during collector start-up were reported by site personnel for two installations. In one case of an evacuated-tube system, leakage occurred at the fittings connecting the collector tubing and system manifold. Leaks were stopped by tightening of the fittings. In addition, lack of adequate space for movement of the collector tubing, due to thermal expansion of the manifold piping, resulted in crimping of the tubing (figure 2.7). The tubing was pressed against the housing of the piping manifold when the piping expanded. The problem was reportedly corrected by providing adequate space for expansion in the manifold housing. In one other evacuated-tube system, soldered joints between the collector tubing and manifold piping leaked during start-up. Resoldering of the joints eliminated the leaks.

- No materials-related problems concerning the storage systems were observed during the visits or reported by site personnel.

2.4 COVERS/JACKETS

- Cover plates on one of the two flat-plate collector systems were glass. The second flat-plate system had three types of covers: glass, polycarbonate, and glass reinforced plastic. No cover plate breakage was observed at either site. Dust and dirt accumulation was present on the covers at both installations. A sprinkler system had been installed at one system to wash the cover plates.

- The flat-plate system containing the three types of cover plates was originally constructed using a continuous thin sheet of polycarbonate, approximately 55 m (180 ft) in length. Replacement of the original polycarbonate was made in the summer of 1980 which was only a few months prior to the site visit. The long expanses of the originally installed polycarbonate sheets were replaced because of reported problems of buckling and cracking associated with lack of adequate provisions for thermal expansion. Glass, polycarbonate, or glass reinforced plastic were reportedly used as replacement covers on an experimental basis to determine which of these three materials might perform most satisfactorily at the system location. Site personnel indicated that when the system was designed, there was reluctance to use glass covers because of possible breakage due to vandalism. Vandalism of the replacement glass had not occurred. In general the materials had been in place too short a time to observe differences in performance. The replacement polycarbonate cover plates consisted of short sheets joined together by overlapping. Some of these overlaps were not tight, and dust and dirt were blown into the joints between sheets and into some collector enclosures (figure 2.8).

- With one exception, the receiver tubes of the six line-focus collector systems had circular glass jackets (figures 2.3, 2.9, and 2.10) or flat covers (figure 2.11). In the case of the exception, there was no jacket on the receiver tube as designed and constructed. Some breakage of the glass had occurred at four sites. At one site, breakage had been attributed to inadequate allowance for thermal expansion. Redesign and replacement of the jacket supports to allow for expansion had corrected the breakage problem, although not all the broken jackets had been replaced. At another site, breakage of glass jackets was attributed by site personnel to the use of a metallic spacer ring around the midpoint of the absorber tube (figure 2.9). The spacer ring was intended as a support for the glass jacket. Upon thermal expansion, the rings scratched the glass, which subsequently broke. Removal of the spacer rings corrected the glass breakage problem. At a third site, semicircular glass jackets were held on insulated receiver tubes using spring clips (figure 2.10). Moisture was present within some sections of the receiver tubes. One small length of a glass jacket, which apparently had no spring clips holding it in place, broke when it fell from the receiver tube during focusing of the collector. The flat glass covers were used in an insulated receiver tube assembly (figure 2.11). In addition to some sections of broken glass, moisture was present on the underside of many of the flat glass covers.

2.5 DRIVE SYSTEMS

- The performance of the drive systems of the six line-focus collectors was variable. For three of the six installations, the drive systems were functioning without any reported problems (figure 2.12). Conversely, in the worst case, all gear boxes of one system were frozen and the collectors could not be turned from the stow position. Reasons for the failure of the gear boxes were not reported, although they apparently leaked fluid. Oil deposits were observed on the roof under the gear boxes (figure 2.13). Excessive movement of the collectors due to faulty tracking may have also

contributed to the failure (section 2.14). At another location, problems occurred with drive systems having undersized motors which operated intermittently. These motors are being replaced with those of proper size which operate continuously. At a third site, one gear box was frozen, while motors on some other gear boxes were described by site personnel as continually blowing fuses. At this site, the gear drive was exposed to the weather (figure 2.14). Site personnel indicated that future installations of this system were planned to have a housing around the gear drive.

2.6 EVACUATED TUBES

- Three of the sites visited had evacuated-tube collector systems. At two of the sites, breakage of the glass evacuated tubes was considered extensive; while at the third site, it was minor (figure 2.15). At this latter site, it was indicated during conversations that about 1 percent of the tubes broke during system start-up and were replaced by the manufacturer. Site personnel attributed breakage to factors such as thermal shock and scratching of the tubes during installation. In one case, site personnel reported that tube breakage occurred when the system became operational after brief interruptions of service for repairs. Vandalism was also a significant cause of tube breakage at one site.

- A number of tubes at the three sites had lost the vacuum as indicated by the white oxidized getter at the tips of the tubes (figure 2.16).

- Site personnel indicated concerns with degradation of the copper fins attached to the heat transfer fluid tubing around which the evacuated tubes are placed. The copper fin degradation was reportedly attributed to oxidation at the temperatures reached during system stagnation. The effect of the fin degradation on the thermal performance of the collectors was not determined during the site visits.

2.7 FLEX HOSES/SWIVEL JOINTS

- Flex hoses (figure 2.17) in the six line-focus systems inspected were operating without problems. At one site, a single flex hose had failed and been replaced prior to the visit. Reasons for the failure of this flex hose were not given.

- One system which was not operational at the time of the visit contained swivel joints (figure 2.18). Some of the swivel joints were reported by site personnel to have leaked during system start-up, but the cause of the leakage was not given.

2.8 FLUIDS

- Three types of heat transfer fluids were used among the systems inspected: water, aqueous glycol, and an aromatic hydrocarbon high temperature oil. The systems using water operated within the range of 66-177°C (150-350°F).

Operating temperatures for the aqueous glycol systems ranged from 57-132°C (135-270°F). The oil system which was under construction at the time of the visit was designed to operate at 186°C (367°F). Line-focus collectors should not stagnate, provided that they de-focus or are placed in the stow position upon exceeding a predetermined maximum temperature of the receiver tube or heat transfer fluid. An evacuated-tube collector may reach 371°C (700°F) or higher upon stagnation. One of the evacuated-tube systems used aqueous glycol as the heat transfer fluid. Information was not available concerning changes in physical and chemical properties of the glycol solutions. With one exception, site personnel did not indicate problems with heat transfer fluids and, as previously discussed, leaks in containment materials were few (section 2.3). One water system was retrofitted with a filter to remove particulates which were clogging valves.

2.9 INSULATION (THERMAL)

- Insulation was used in the sites visited on the backsides of absorber plates and receiver tubes, on transport piping and accessories, and on storage systems. It was generally not possible to observe the insulation because of the covering provided to protect it from the effects of weather. Piping was normally insulated with fiberous glass, although some foam was also used.

- The primary concern raised from the field observations centered on the application which was variable over the sites. Some applications appeared satisfactory in so far as the insulation was protected from moisture intrusion and other weather effects (figure 2.19). Conversely, other applications were found to have deficiencies including: missing protective covering (figure 2.20); improper installation of protective coverings allowing moisture entry into the insulation (figure 2.21); use of sealants which split and cracked; and lack of insulation on accessory items such as valves and flex hoses (figures 2.2 and 2.17).

- The one air system in the field inspection had spray-in-place polyurethane foam insulation on the exposed air ducts. With the exception of vandalism, the coating on the foam appeared through visual inspection to be satisfactory after three years exposure. Vandalism had caused many punctures and splits in the coating and insulation (figure 2.22). Another site had pre-formed foam insulation with a liquid applied coating on manifold pipes. This insulation was not properly protected from the weather, as indicated by its cracked and crazed surface.

- Receiver tubes on three line-focus systems were insulated on the backside (figure 2.10). In two of the cases, the insulation was fibrous glass; the type was not determined in the third case. Since the insulations could not be observed because of encapsulation, their condition could not be evaluated. Concern was expressed as to the thermal stability of the insulations in contact with receiver tubes.

2.10 PUMPS

- Pump failures had occurred at some of the sites. In one case, the system was inoperable because a failed pump had been removed and not replaced. In

other cases accounts of pump failures which had been corrected before the site visits were reported by site personnel. These failures were generally attributed to the seals, but further information was not provided. In one case, pump failure occurred because of packing which was too tight.

2.11 RECEIVERS (LINE-FOCUS SYSTEMS)

- At one line-focus installation, site personnel indicated that bending of some of the metallic receiver tubes had occurred when the receivers were in focus with low flow rates of the heat transfer fluid. This condition resulted in excessive receiver temperatures (figure 2.23). The bent receiver tubes were being replaced at the time of the visit.

- At one site the ends of the receivers were not sealed between the absorber pipe and glass jackets. Some dirt had blown into the receivers at these locations.

- At another site, receivers of an inoperable line-focus system contained some split copper pipes and broken glass covers. A cause of split pipes may have been freezing of water which was not drained from the non-operating receivers.

- Receiver tubes at some installations had short uninsulated sections extending beyond the glass jacket in the vicinity of the supports (figure 2.24).

2.12 REFLECTIVE SURFACES

- Three types of reflective surfaces were used at the six line-focus installations: two systems had second surface glass mirrors, two had polished aluminum, and two had metallized plastic film. Two evacuated-tube systems used polished aluminum, and the third evacuated-tube system had a metallized plastic film. At one site with glass mirrors, desilvering had occurred and was particularly extensive along the mirror edges (figure 2.25), perhaps due to moisture penetration at those locations. Breakage of the mirrors was also evident at this site (figure 2.25). Site personnel indicated that the glass mirrors were to be upgraded with a metallized plastic film because of the extent of desilvering and breakage. Mirrors at the other site appeared in good condition.

- The polished aluminum reflective surfaces of both line-focus and evacuated-tube systems were generally in good condition, although dulling had occurred at some sites. For example in one case, two sections of evacuated-tube collectors had been removed from the site to determine, by laboratory measurements, whether the dulling had reduced collector efficiency.

- Visual evidence of abrasion of the front surfaces of the metallized plastic films was not seen at the three sites having such reflective surfaces. Some delamination of metallized plastic films was observed at two of the sites. In one case, small areas of delamination, about 13 mm (1/2 in.) in width, ran horizontally from one end of the trough to the other (figure 2.27). In the second case, delamination of the metallized plastic film was from the longitudinal edge of a single trough toward its center. The film apparently

was delaminated when a plastic strip sealing the edge of the collector fell from the trough and pulled the film from the surface (figure 2.28). Blisters raised slightly from the substrate were also observed on areas of the trough surfaces other than the edges. Many of these blisters were located in areas corresponding to screw penetrations on the back of the troughs. It was not determined whether the screw penetrated the trough surface under the reflective film. At the third site, where construction of the collector system was essentially completed, the metallized plastic film appeared in good condition.

- Dirt, dust, and other particulate accumulation on the reflective surfaces was a problem common to all sites visited (figures 2.29 and 2.30). Reduction in collector efficiency because of soiling of the reflective surfaces was of concern to many site personnel. Cleaning procedures such as the use of hoses, sprinkler systems, and the hiring of professional washers had been initiated at many sites to remove accumulated particulates from the reflective surfaces. At some locations, site personnel indicated that line-focus collectors were turned upwards during rain storms to wash the reflective surfaces. It was also indicated that placing the line-focus collectors in the stow position when not in use reduced the accumulation of dirt and dust.

- Vandalism at one evacuated-tube installation (see section 2.6) had resulted in punctures and dents in the metallized plastic reflective film and damage to the troughs and tubes.

2.13 SEALS (RUBBER)

- Rubber seals* were not used to any extent in the systems visited. At one site, rubber o-ring seals were originally installed at the ends of the receivers between the absorber tubes and glass jackets to protect against dirt and moisture entry (figure 2.31). According to site personnel, the temperature of the o-rings exceeded the design limits due to concentration of the solar radiation on the seals when the collectors were in focus. The excessive temperature reportedly resulted in deterioration of the seals. An expedient temporary correction of the problem was accomplished by installing reflective tape on the receiver jacket at the o-rings to prevent absorption of the concentrated solar radiation by the seals and excessive temperatures at those locations. Site personnel indicated that a metal seal was being designed to replace the o-rings as a permanent correction of the problem.

- At one line-focus installation, pre-formed rubber gaskets were used to seal the flat glass covers to the insulated receiver assembly (figure 2.11). Some of the gaskets were seen to be deformed and have buckles, and thus were not tight against the flat glass covers.

- Sealants were used in many systems to prevent water penetration into thermal insulations at piping system locations such as joints, couplings, fittings and valves. In many cases, the sealants were seen to have split and cracked (figure 2.32).

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* The term, rubber seal, is used generically to indicate elastomeric materials.

2.14 TRACKERS

- In the case of the two operational parabolic trough line-focus systems visited, the collectors at each individual site were oriented in the same direction towards the sun. Quantative information regarding tracking accuracy was not obtained during the field survey.

- A concern to site personnel at some line-focus systems having shadow band trackers was the irregular tracking of the collectors under conditions of low solar radiation and random cloud cover. Under these conditions, when the clouds cover the shadow band trackers for short intervals of time, the collectors rotate in an attempt to find the sun. If the sun is not found, the collectors may go to the stow position. This irregular behavior of the tracker was experienced at one site during the field inspections. At another location, site personnel indicated that excessive searching of the collectors, due to trackers functioning improperly, may have been responsible in part for failure of the system gear boxes. As previously mentioned (section 2.5), this system was inoperational because of frozen gear boxes.

- At one site, moisture had entered into the shadow band trackers due to holes in the tracker housings (figure 2.33). Site personnel indicated concerns that the entrapped moisture would result in failure of the trackers. The trackers with moisture were to be replaced. One replacement tracker was installed prior to the site visit and did not show moisture in its interior.

2.15 TROUGHS (PARABOLIC)

- In the case of one line-focus collector having parabolic troughs, plastic strips used as molding to seal the edges of the troughs (aluminum honeycomb sandwiches) were delaminating (figure 2.34). These molding strips were brittle. The delamination of the edge moldings exposed the interior of the troughs to moisture.

- At one site, the back surface of one collector trough was not protected from hot sparks and solder from welding operations during system construction. The trough had pitted areas where the sparks landed on the rear surface.

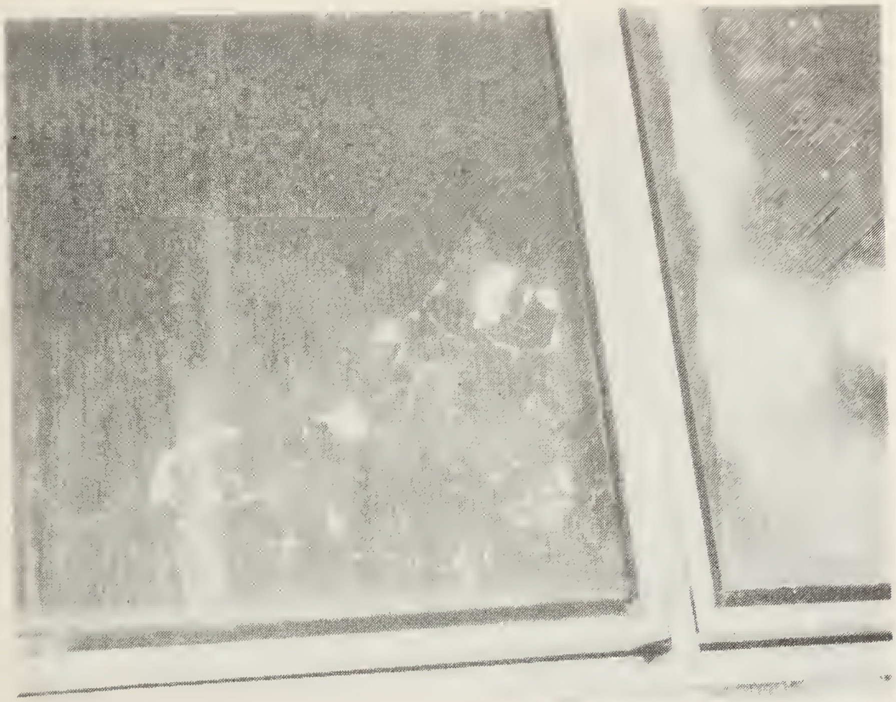

Figure 2.1. Peeling and cracking of absorptive coating and moisture on the underside of the cover plate

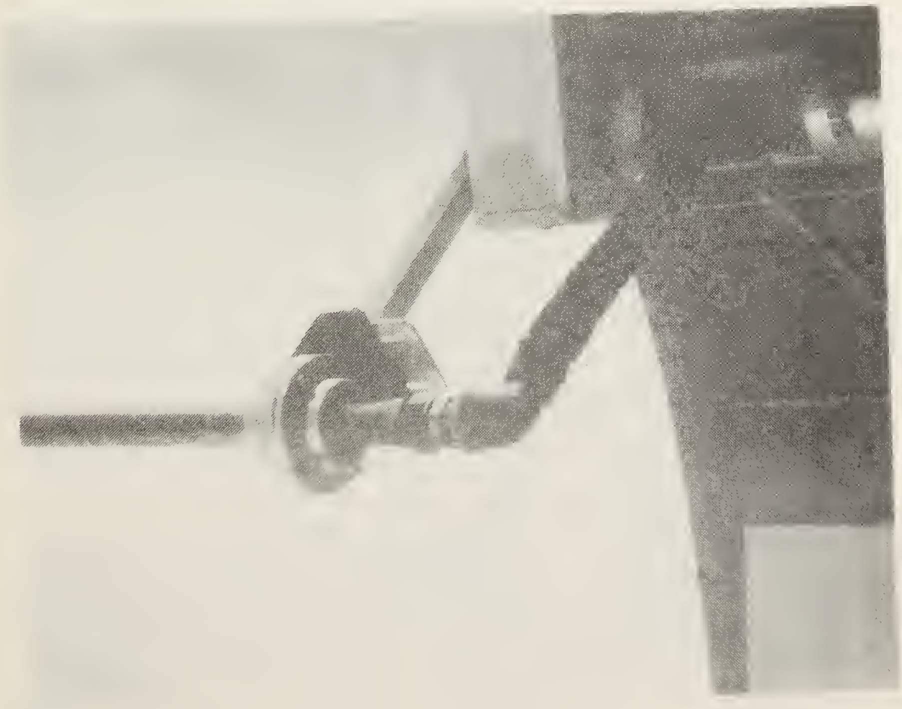

Figure 2.2. Receiver tube without glass jacket exposing the absorptive coating to the weather

Figure 2.3. White deposits on absorptive coating of receiver tube

Figure 2.4. White deposits on absorber plate and rivets, and moisture on the underside of the cover plate

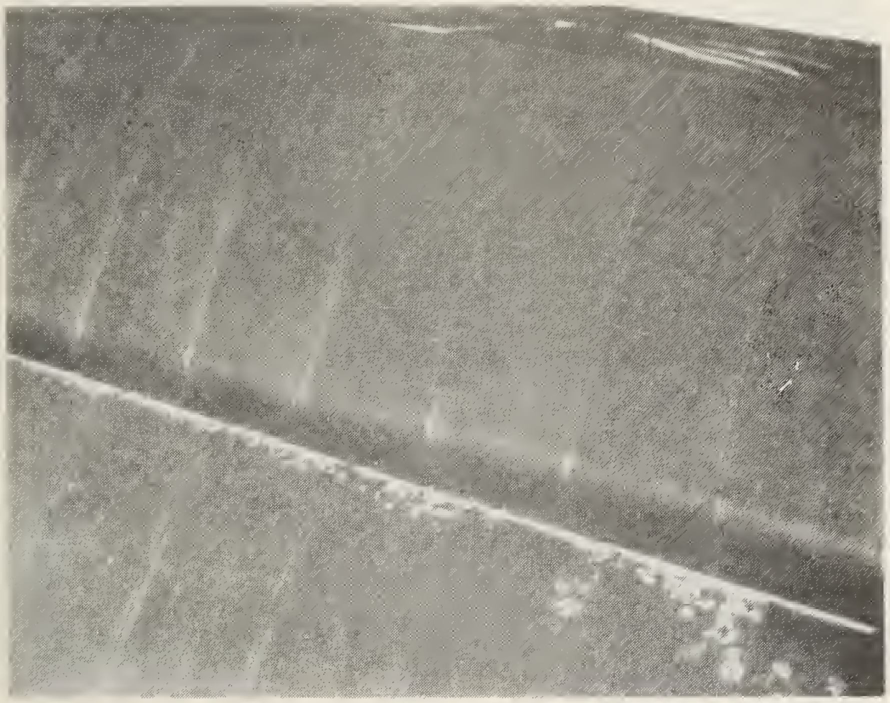

Figure 2.5. White deposits on upper section of the absorber ducts of an air system

Figure 2.6. Corrosion of an elbow fitting connecting a metal flex hose and a receiver tube

Figure 2.7. Crimped tubing removed from collectors

Figure 2.8. Inadequately sealed joint between cover plates allowing dust and dirt penetration into the collector

Figure 2.9. Metallic spacer ring on absorber tube

Figure 2.10. Spring clip holding jacket on a receiver tube and moisture on the underside of the jacket

Figure 2.11. Insulated receiver tube assembly having a flat glass cover plate

Figure 2.12. Drive system of a line-focus collector

Figure 2.13. Oil deposit on the building roof under the collector gear box

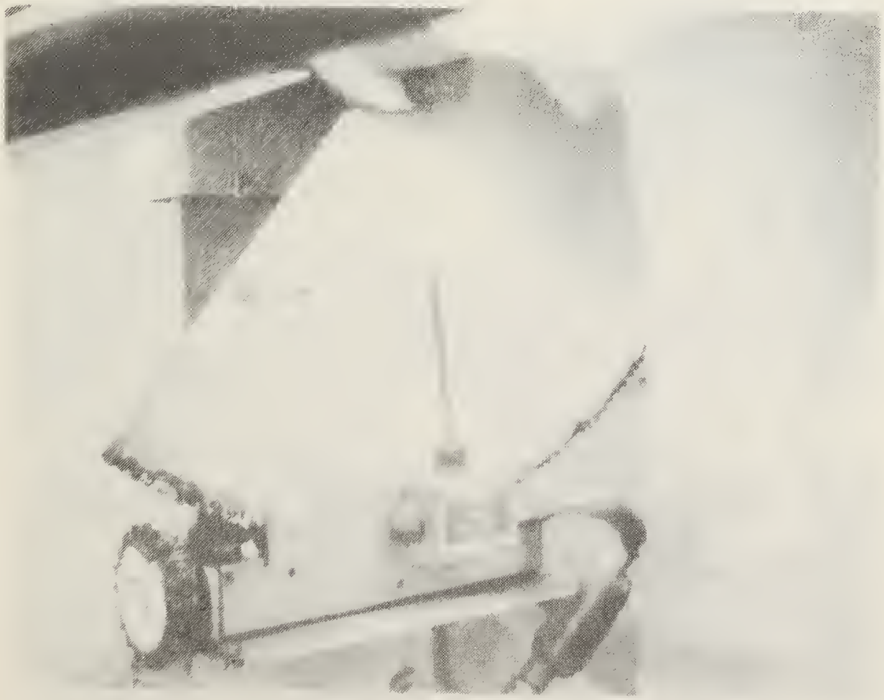

Figure 2.14. Exposed gear mechanism

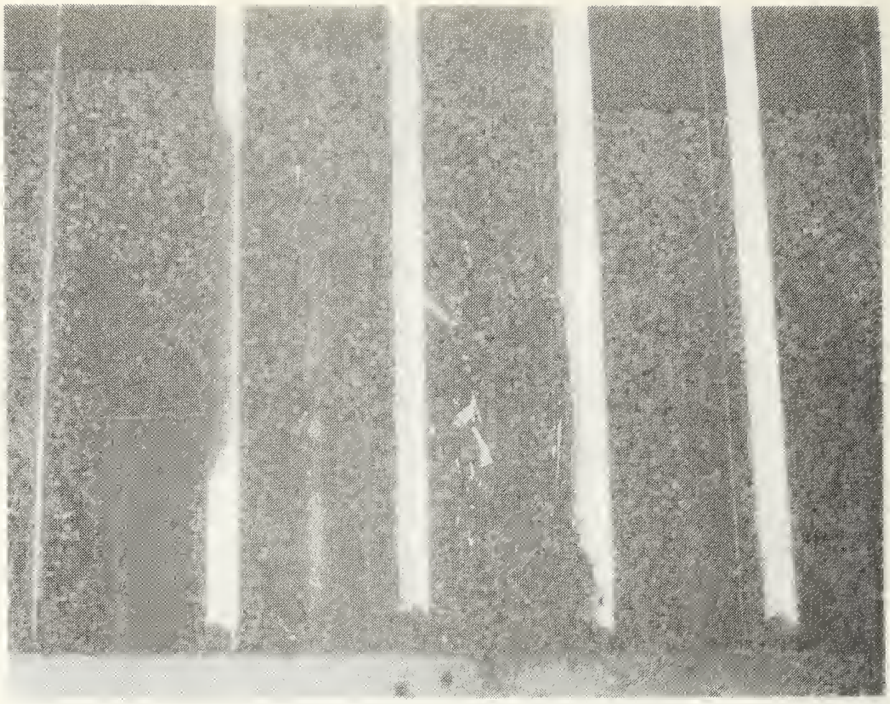

Figure 2.15. Breakage of evacuated tubes

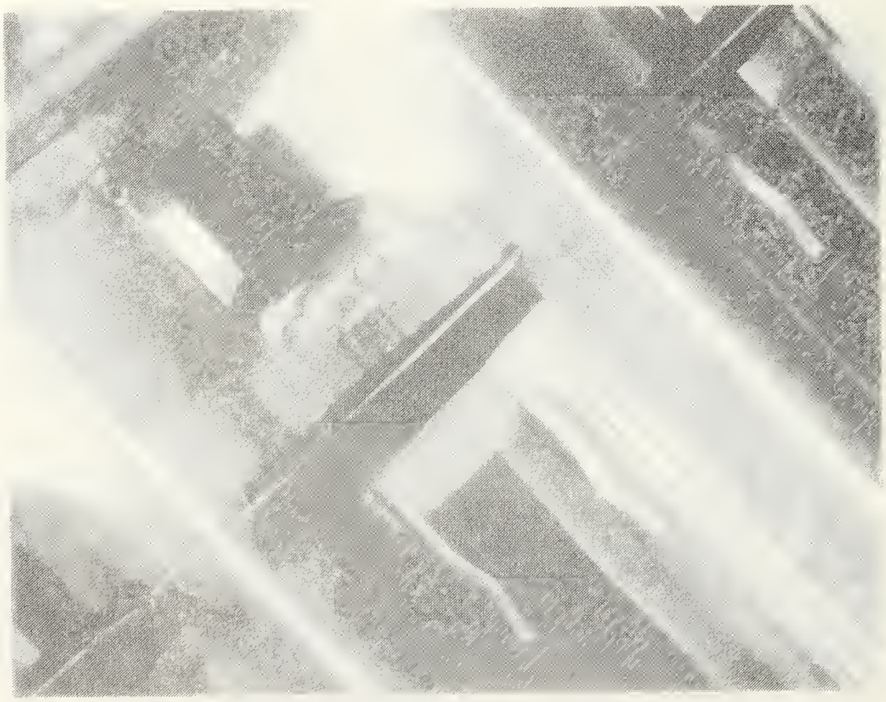

Figure 2.16. Loss of vacuum in an evacuated tube

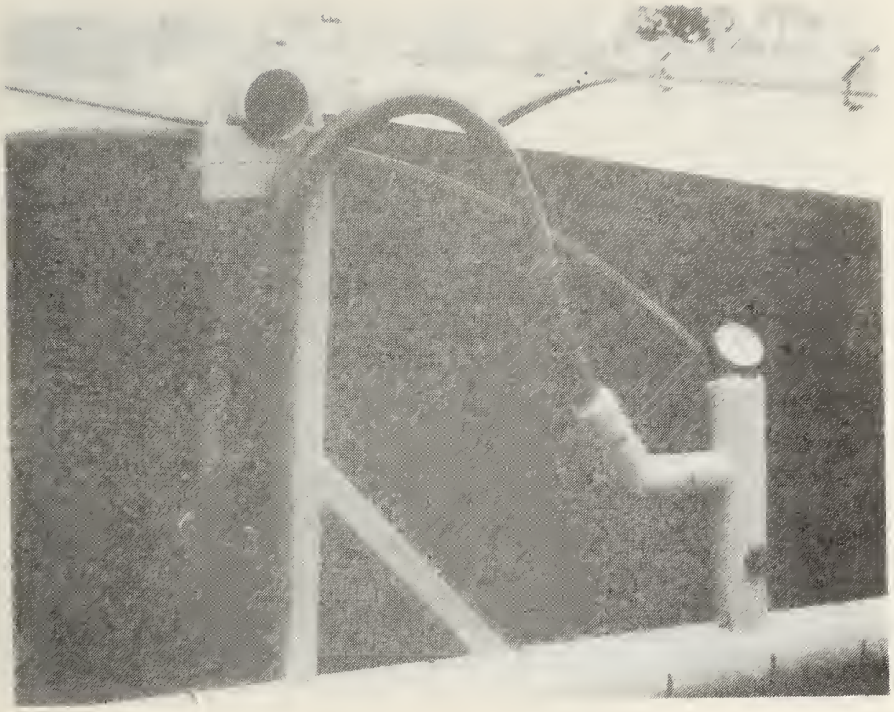

Figure 2.17. Flex hose of a line-focus system

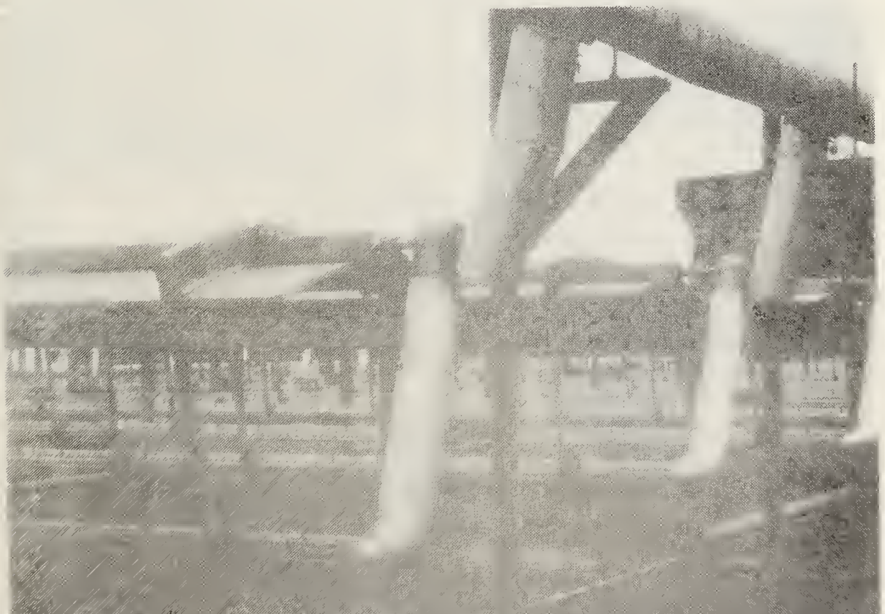

Figure 2.18. Swivel joint of a line-focus system

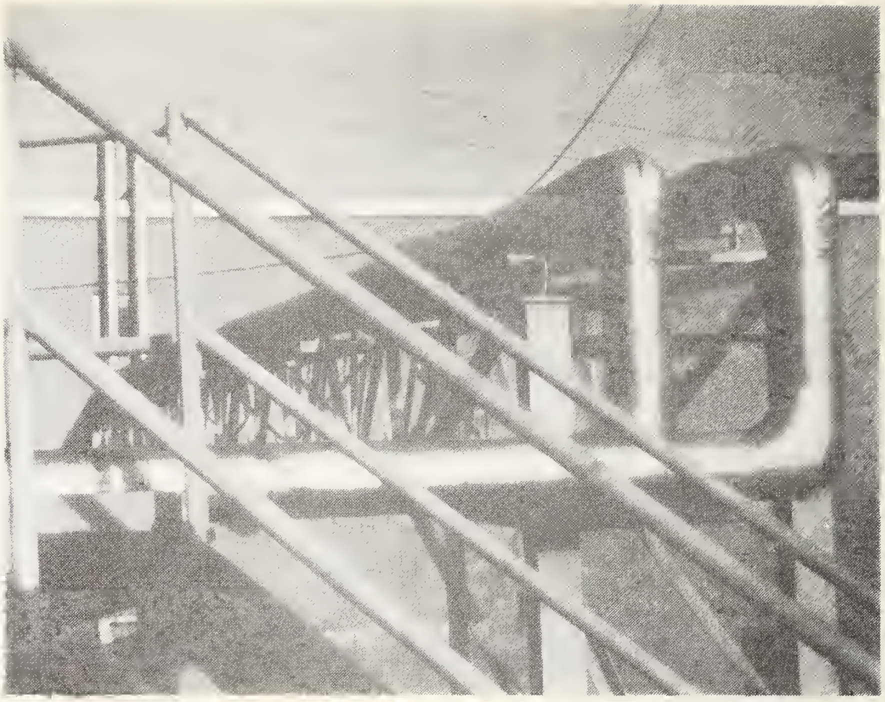

Figure 2.19. Insulated piping transporting heat transfer fluid to and from the collector field

Figure 2.20. Exposed fibrous glass insulation

Figure 2.21. Failure of protective covering on insulation

Figure 2.22. Punctures in spray-applied polyurethane foam and its protective coating due to vandalism

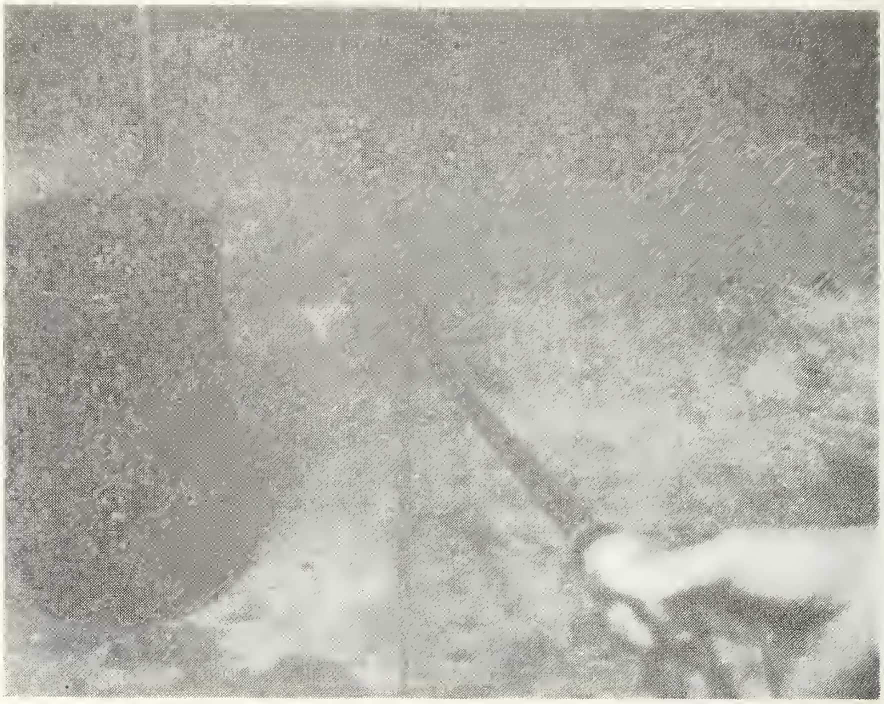

Figure 2.23. Bent receiver tube due to excessive temperatures

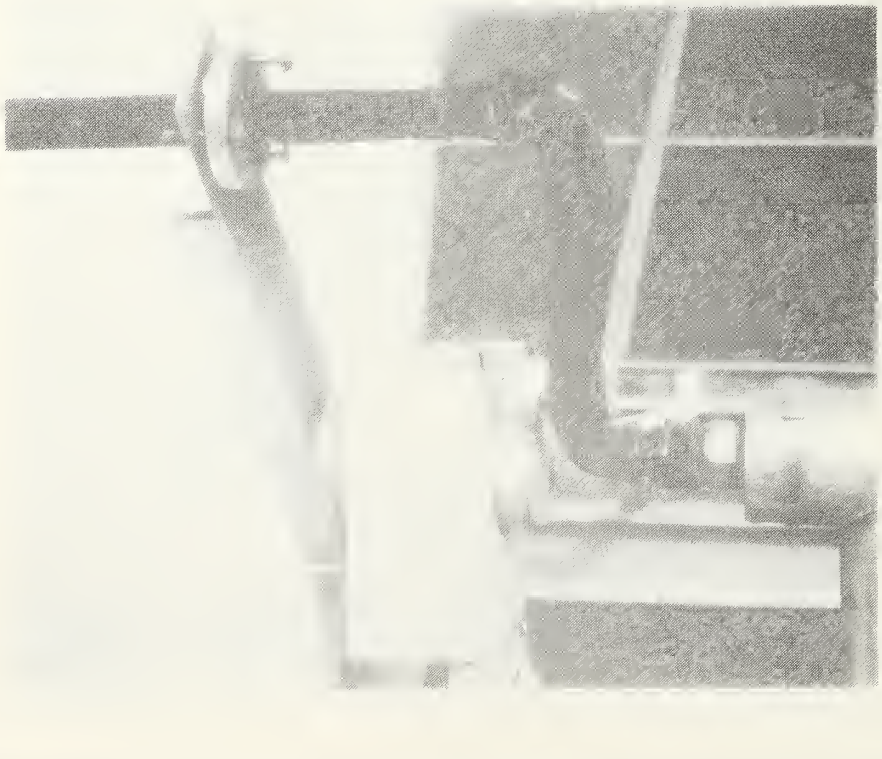

Figure 2.24. Short section of uninsulated receiver tube

Figure 2.25. Desilvering of exposed glass mirrors

Figure 2.26. Broken glass mirror

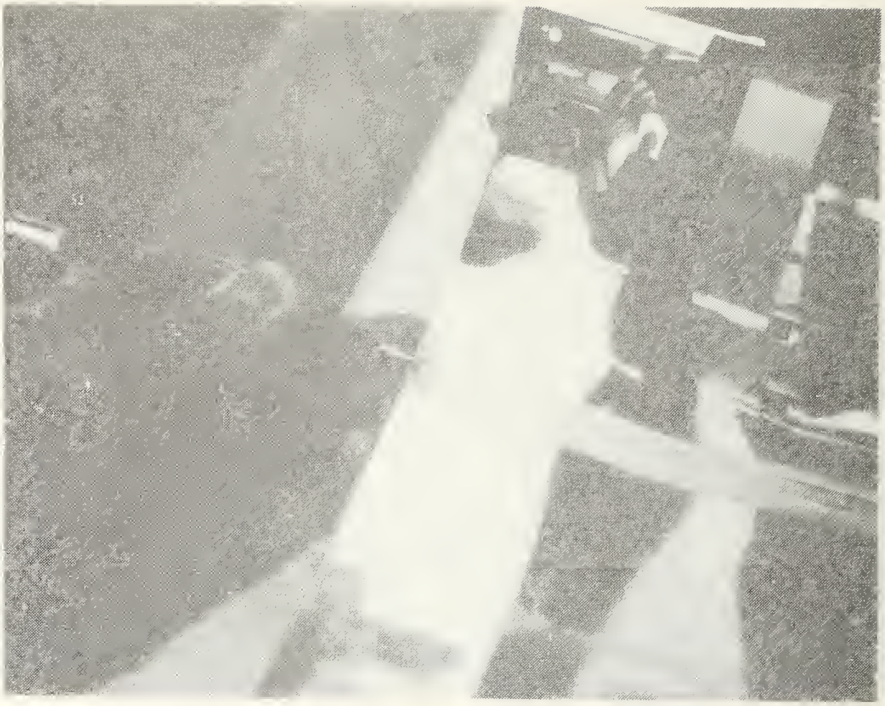

Figure 2.27. Delamination of a small area of metallized plastic film

Figure 2.28. Delamination of a metallized plastic film at the edge of a trough

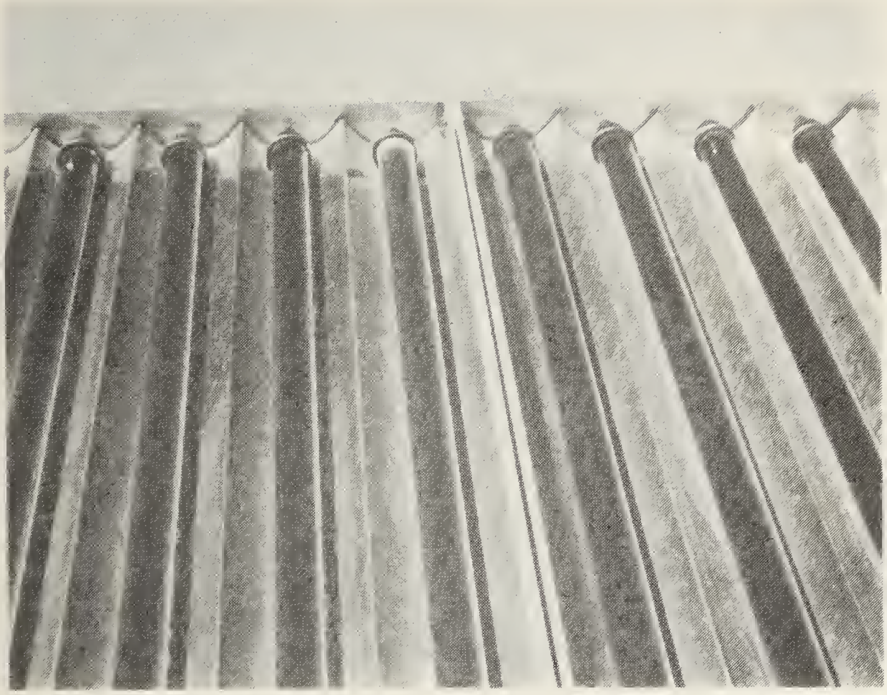

Figure 2.29. Dust and dirt on the surface of an evacuated-tube collector

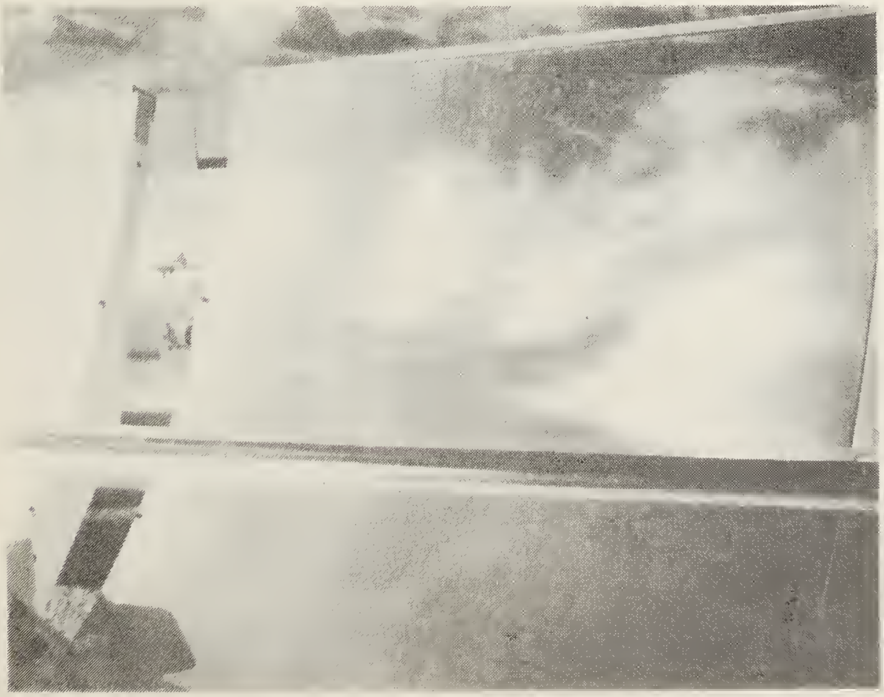

Figure 2.30. Dust and dirt on the reflective surface of a parabolic trough

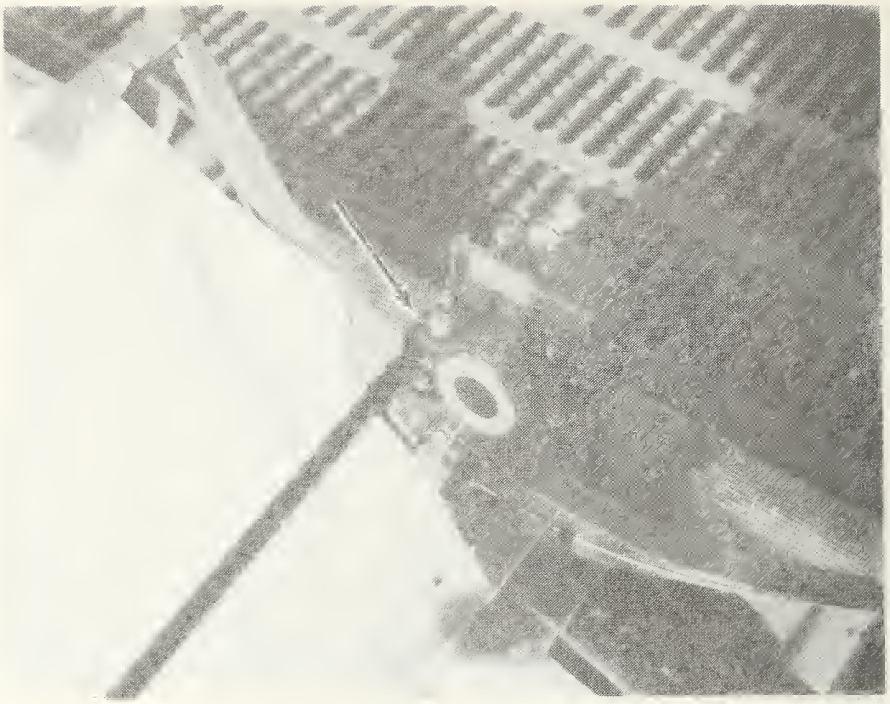

Figure 2.31. O-ring seal at the end of an absorber tube

Figure 2.32. Cracking of a sealant used to protect against moisture penetration into thermal insulation

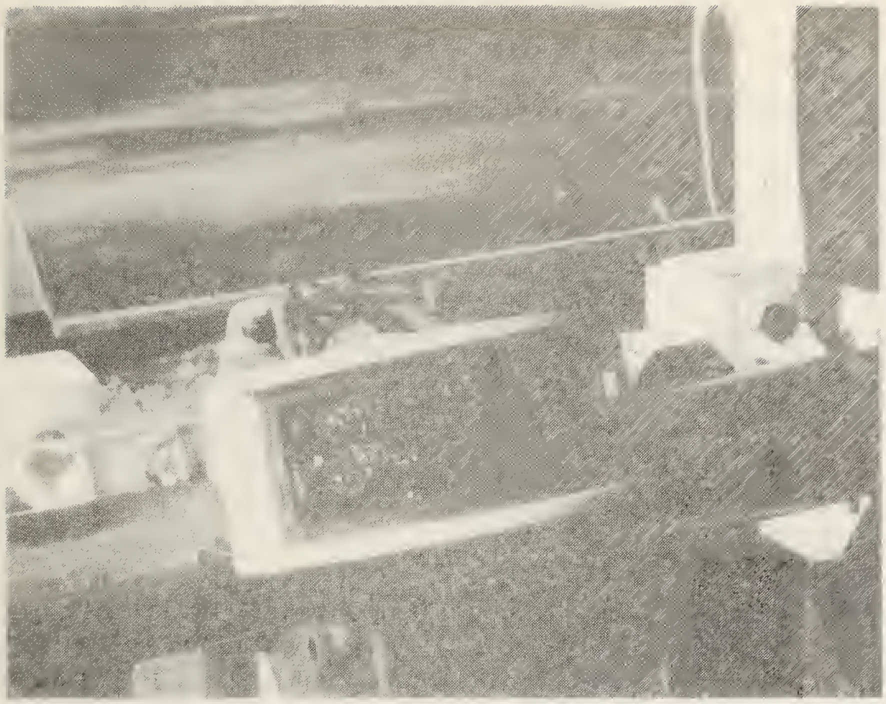

Figure 2.33. Shadow band tracker having moisture within the housing

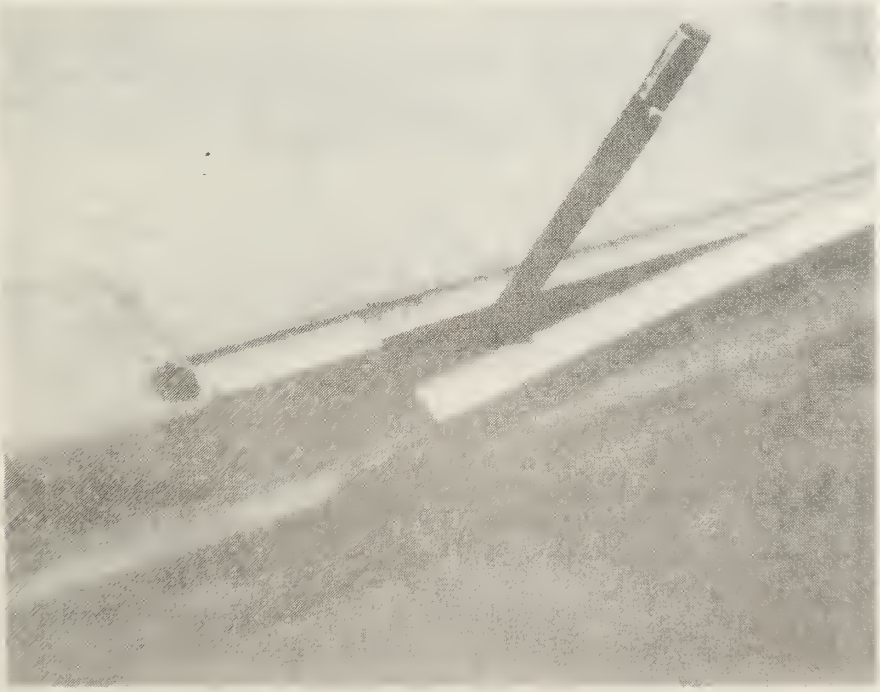

Figure 2.34. Delaminated plastic strip at the edge of a trough

3. ADDITIONAL INFORMATION RELATING TO IPH MATERIALS AND COMPONENTS PERFORMANCE

3.1 THE LITERATURE

The dissemination of information regarding the design and in-service performance of IPH solar systems is an integral part of the IPH program. A number of proceedings and reports have been published to allow the industry to share its experiences and to learn the results of ongoing research and development. A review of the literature was conducted as part of this study to evaluate the need for standards for materials and components for IPH systems. A summary of the literature considered pertinent to the development of standards is given in this section of the report. It was beyond the scope of the project to present a comprehensive review of current research and published papers.

3.1.1 Conferences and Workshops

A series of conferences on solar IPH technology have been held, and the proceedings have been published [8-12]. The proceedings provide an overview of the IPH program and include papers on system design, economic analyses, potential industrial processes for solar applications, field experiences, and research results. Descriptions and status reports of the demonstration projects are included in the proceedings. The status reports for operational systems mention materials and components problems which have occurred in service, and remedial actions taken to correct them. The materials problems reported in the proceedings were among those observed in the field survey conducted during this study (section 2).

The proceedings of a workshop on the reliability of materials for solar energy systems have been published [13, 14]. Some papers addressed materials used for IPH systems including absorber coatings, mirrors or other reflective surfaces, transport systems and heat transfer fluids. The development of methods for materials evaluation and the preparation of industry standards and design rules for solar technology were among the recommendations listed in the workshop.

A workshop devoted solely to IPH processes was held in 1976 [15]. The theme of the workshop was the feasibility and potential applications of the use of solar energy for industrial processes. Papers were presented on the design of the early IPH field test projects. Many recommendations were made concerning future research and development needs for the industry with regard to collectors, storage, and systems. However, the proceedings made little reference to the performance of materials in IPH systems.

In late 1980, a seminar was held on the development of line-focus solar thermal energy technology [16]. In contrast to the 1976 IPH workshop, the 1980 seminar included sessions concerned with the development and performance of materials and components for line-focus collectors. Papers on materials performance were presented on the subjects of black chrome, glass fiber reinforced concrete for troughs, silvered glass mirrors, and polymer reflectors. The prediction of the service-life of components was also discussed. It was indicated that accelerated aging studies are needed for making reliable predictions of service-life,

since the systems and technology are in the relatively early stages of development.

The proceedings of the second conference on absorber surfaces for solar receivers has been published [17]. The main topics of the conference were: the development of microstructural models for black chrome selective solar absorbers; the stabilization of black chrome for applications to 350°C (662°F); and the laboratory development of cermets for application to 600°C (1112°F). Although intended as a conference topic, the field exposure and durability of absorber coatings were not discussed. The conference proceedings contained an appended bibliography of papers related to absorber surfaces.

The performance of solar reflective materials has also been the subject of a workshop [18]. The workshop focused on problems regarding the durability of superstrates, reflective layers, and protective layers of heliostat mirrors. The workshop objective was to assess research efforts to understand and control the degradation process which mirrors have undergone after relatively short periods of field service. The major topics addressed at the workshop were: the effects of environmental contamination; glass and mirror production processes; the environmental stability of glass superstrates; analysis of silver-glass second surface mirror degradation; the experience with and potential of polymer mirror systems; and advanced mirror protection concepts. Among the general conclusions from the workshop, it was indicated that: adhesion mechanisms of dust on mirrors are not well understood; research into glass production processes would improve efficiency and durability; mechanisms for silver-glass mirror degradation are mainly speculative; and, improvements in polymer technology have shown a potential for using highly specular polymer mirrors [18].

Another workshop on solar surfaces addressed the problem of soiling of reflective surfaces by air-borne particulates and aerosols [19]. The magnitude of the effect of the air-borne contaminants on the reduction of surface reflectivity was dependent upon the design of the optical system, the nature of the contaminants at the exposure site, the seasonal climate at the site, the material comprising the optical surface, and the method of removal of contaminants from the surface. Recommendations for research were given including obtaining data on the rate of dust accumulation for various materials and locations, and the development of a quantitative method for predicting the soiling effects on solar concentrators from local pollution and climate data.

3.1.2 Handbooks and Field Experience

Kutscher and Davenport published a report describing the preliminary operational results of the six low-temperature solar IPH field test installations [20]. Observations from the field showed materials and components problems such as degradation of absorber surfaces and glazings, thermal shock of evacuated tubes, mirror breakage and desilvering, water seepage into insulation and overheating of plastic pipe. The authors considered that the observations would be useful to the design of future projects. Among their conclusions they indicated that "problems similar to those encountered in solar heating and cooling of buildings programs occur in IPH applications [20]."

The "Solar Heating Materials Handbook" has been prepared to provide solar designers assistance in the selection of appropriate materials [21]. Emphasis is placed on the consideration of environmental and safety factors during materials selection. Solar materials included in the handbook are heat transfer fluids, glazing, insulation, seals and sealants, thermal storage media, and absorber materials. Values of properties considered important to performance are given for specific materials.

A listing of the factors to be considered in each aspect of the design of solar IPH systems has been given [7]. The factors listed were based on information learned in the design and operation of the IPH field test installations. The purpose of the document was to take advantage of the field experiences in order to help prevent recurrence of past problems in future systems. Factors listed for consideration during design included the following topics: system application, overall system design, design of individual components, instrumentation, and controls, installation, prediction of the energy delivered, economics, data acquisition, and safety.

A forecast of solar IPH technology in the year 2000 has been prepared by Prythero and Meyer [22]. They predicted that the selected IPH system will consist of line-focus parabolic trough collectors. Material components were predicted to be based upon existing and anticipated future technological developments. Technologies considered to have significant impact on future IPH systems include glassmaking, silvering, electroplating, and plastics forming.

3.1.3 Research Related Publications

The National Bureau of Standards has a laboratory research program intended to aid in providing the technical basis for consensus standards for assessing performance and durability of solar materials in flat-plate collector systems [23]. Materials studied include absorptive coatings, metallic and non-metallic containment materials, cover plates, rubber hose, thermal insulation, and seals. A number of NBS publications are available from the studies [24-29]. Standards for some materials such as absorber covers, hoses, seals, and metallic containment materials have been developed by the American Society of Testing and Materials (see section 4).

The mid-temperature solar system test facility is located at the Sandia National Laboratories. A status report of the facility's activities gives a summary of ongoing research projects for the development of mid-temperature solar technology [30]. Areas of materials research include mirror cleaning, heat transfer oil aging, black chrome thermal aging, flex hose testing, trough components life testing, and long-term evaluation of receivers.

The Solar Energy Research Institute is developing an outdoor test facility for "Solar Energy Research and Applications in Process Heat" for evaluation of solar IPH systems [31]. The performance of complete small-scale systems will be monitored in a closely controlled environment. A primary objective of the facility is to verify materials performance as part of an operational system.

The technical support for solar applications for buildings provided by the Los Alamos Scientific Laboratory to DoE has been described in a progress report [32]. Collector and materials projects funded by DoE have been monitored. Fifteen projects concerned with the development of concentrating collectors, while twenty-nine dealt with research and development of materials including absorbers, glazings and coatings, fluids and corrosion, insulating materials, and sealants. Research at the laboratory was centered on testing of evacuated-tube collectors, and selective coated metal foils for use in these types of collectors.

Finally, the design reports (often called Phase I reports) for the field test installations in the DoE industrial process heat program should be mentioned. These reports provide information concerning system design and materials selection. In general, the design reports indicate that standardized evaluative test procedures were seldom used for the selection of many materials and components in the systems. Subjective value judgments played a major role in the selection process.

3.2 DISCUSSIONS WITH INDIVIDUALS IN THE INDUSTRY

During this study, discussions were held with solar system manufacturers' representatives, architects, plant engineers, designers, consultants, and other individuals in the solar IPH industry. The purposes of the discusssions were to review these individuals' experiences concerning the performance of materials and components and to ask their opinions concerning the need for standards for IPH materials and components. With regard to materials performance, the discussions indicated that many individuals in the industry were aware of the problems that had occurred in the field test program. Moreover, manufacturers were aware of the specific problems with their systems which were observed in the field survey (section 2).

Most individuals contacted in the industry indicated that the development of standards including materials specifications and evaluative test methods would be beneficial. However, many of the opinions concerning the benefits of standards development were qualified. Comments from the industry were at times contradictory, because of the various opinions held by different individuals. It is of interest to note some of the following industry comments and opinions concerning standards development:

- Priority in standards development should be given to key materials and components of the system; for example, reflective surfaces and absorber coatings for line-focus collectors.

- Although standards development would be beneficial, the time is too early; the industry is still developing. Preparation of standards for materials and components under development is not critical.

- Standards development should be initiated for materials and components which are forecast to be used in the industry for a long time.

- For many non-solar specific components, for example, steel support members, pipes, nuts, and bolts, material standards are available to the solar system designer.

- Standards should be non-restrictive in that they should not preclude the use of materials in situations where they would perform satisfactorily.

- Test method development is not practical at this time, since insufficient data are available on solar materials and component performance under a variety of environment conditions. Test exposure conditions and criteria need to be precisely selected, if the test results are to be correlated reliably with in-service performance.

- A need exists to develop service-life prediction techniques so that long-term materials performance may be readibly assessed from short-term tests.

- Lack of standards in the industry is detrimental to designers and manufacturers selling collector systems with warranties. The designers may select materials which were inadequately assessed because of the lack of evaluative procedures. These materials are then incorporated into systems for which the solar manufacturer, and not materials supplier, has warranty responsibility.

- The availability of standards for key components would eliminate the use of marginal materials.

- Standards availability would be of little importance to architectural-engineering firms which specify predesigned and engineered collector systems from a solar manufacturer. In these cases, the architect-engineer may base the selection of the system on the reputation of the solar manufacturer.

From the discussions, the lack of materials standards including evaluative test methods was seen to have an adverse effect on the materials procurement process. Many solar designers indicated that standards would have been useful in selecting solar-specific materials and components. These individuals stated that they used available standards for the non-solar specific materials and components included in their systems.

In cases where standards were not available, the designer might prepare a specification for the given material based on his own experience gained from designing products in technological fields other than solar energy (e.g., aerospace). Designers mentioned that in some instances, non-standardized laboratory tests were conducted on materials considered for solar applications. One designer indicated that laboratory tests of materials were expensive, time-consuming, increased the cost of the solar installation, and were not always successful. In some cases, designers choose trade name products and made value judgments basing their decision in part on the reputation of the material manufacturer.

4. STANDARDS FOR MATERIALS AND COMPONENTS OF SOLAR IPH SYSTEMS

Standards may be classified into various types including: materials specifications; test methods for determining materials properties; practices for evaluating materials performance under given exposure conditions; and practices for materials applications and use. Test methods for materials properties and evaluative practices are of major interest within the scope of this report. In considering the evaluation of materials for IPH solar applications, the type of material, its use and function in the system, and the exposure conditions during service must be considered. Test methods are selected to determine values of key material properties. Standard evaluative practices should expose the materials to conditions simulating those anticipated in-service. After exposure, values of key properties may be remeasured to determine the effect of the exposure.

Skoda and Masters have previously listed test methods for the common materials used in solar energy systems: coatings, fluids, glass, insulation, metals, plastics, and rubbers [5]. The lists of test methods are reprinted in appendix B, since reference to them is made within this section of the report. It is not the intent to review the applicability of these test methods to the evaluation of solar materials; this has been accomplished. The key needs identified by Skoda and Masters regarding standards for materials for solar heating and cooling systems were the development of accelerated aging tests for the estimation of long-term servicability.

Table 3 presents a list of components of solar IPH systems, as well as the function of each component in the system, and materials from which the component may be fabricated. The components are listed in alphabetical order. An assessment of available standards for each component is summarized in the upcoming subsections of the report. Based on the assessment, the needs for standards development for each component are given. The needs provide in part the basis for the recommendations in section 6.

The American Society for Testing and Materials (ASTM) has issued a number of standards for solar energy materials and components, as shown in table 4. The ASTM also has under consideration draft standards on other aspects of materials and component performance including polymeric containment materials, covers, stability of aqueous heat transfer fluids, thermal insulations, and membrane liners for water tanks. As part of this study, the ASTM approved standards were examined for their applicability to IPH systems. In addition, some Federal and military specifications were also reviewed for applicability (table 5).

4.1 ABSORPTIVE MATERIALS

4.1.1 Assessment

The key performance properties of absorptive materials are absorptance, emittance, and adhesion. Appendix table B.1 presents test methods for evaluating many properties of coatings including optical and adhesion properties. Absorptive materials used in flat-plate and concentrating collectors are

Table 3. Components for Solar IPH Systems, Their Function, and Materials

Component	Function	Materials
Absorptive Coatings	Absorb solar radiation, converting it into heat	Black paint and metallic compounds on metal absorber panels, or on glass or metal tubes
Containment Materials	Provide enclosure for heat transfer fluids or heat storage materials	Glass, metals, plastic, rubber
Covers/Jackets	Provide environmental protection and reduce thermal losses	Plastic, glass
Drive Systems	Move and maintain parabolic trough collectors in the desired position (focus or stow) to provide smooth tracking and stability during gusts of wind	Electric motors with mechanical or hydraulic drive
Evacuated Tubes	Absorb solar radiation and minimize thermal losses from the absorber	Glass
Flex Hoses/Swivel Joints	Provide a flexible connection between tracking receiver tubes and stationary piping headers	Metals, plastics, rubber
Fluids	Transfer heat from the absorber to storage or use	Air, water, glycols, hydrocarbons, silicones
Insulations (Thermal)	Reduce heat loss from components such as collectors, transport systems, and storage	Mineral, organic fibrous, and cellular materials
Pumps	Circulate heat transfer fluids	Metals, rubber seals
Receiver Tubes	Provide a surface for the absorptive coating and containment of the heat transfer fluid which may operate at elevated temperature and pressure	Glass, metal
Reflective Surfaces	Redirect the solar radiation so that it concentrates on the receiver	Polished metals, metallized plastic films, glass mirrors (adhesives for bonding)
Seals	Prevent leakage (air and moisture) into collector or other enclosure	Rubbers
Trackers	Sense the sun's position in relation to the collector to activate the drive mechanism to maintain focus of the concentrated solar radiation on the receiver tube	Photocells, heat-flux sensors
Troughs (Parabolic)	Provide adequate support and a smooth substrate for the reflective surface	Metals, plastics, composites

Table 4. ASTM Standards Relating to Solar Materials and Components

Materials/ Components	ASTM Designation	Title of the Standard
Absorber Panels	B 638	Specification for Copper and Copper-Alloy Solar Heat Absorber Panels
Absorptive Materials	E 744	Practice for Evaluating Solar Absorptive Materials for Thermal Applications
	E 781	Practice for Evaluating Absorptive Solar Receiver Materials When Exposed to Conditions Simulating Stagnation in Solar Collectors With Cover Plate(s)
Collector Assembly	E 823	Practice for Nonoperational Exposure and Inspection of a Solar Collector
Containment Materials	E 712	Practice for Laboratory Screening of Metallic Containment Materials for Use With Liquids in Solar Heating and Cooling Systems
	E 745	Practice for Simulated Service Testing for Corrosion of Metallic Containment Materials for Use With Heat Transfer Fluids in Solar Heating and Cooling Systems
Cover Materials	E 765	Practice for Evaluation of Cover Materials for Flat Plate Solar Collectors
	E 782	Practice for Exposure of Cover Materials for Solar Collectors to Natural Weathering Under Conditions Simulating Operational Mode
Optical Properties	E 408	Test for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques
	E 424	Test for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials
	E 434	Test for Calorimetric Determination of Hemispherical Emittance and the Ratio of Solar Absorptance to Hemispherical Emittance Using Solar Simulation
Rubber Hose	D 3952	Specification for Rubber Hose Used in Solar Energy Systems
Rubber Seals	D 3667	Specification for Rubber Seals Used in Flat-Plate Solar Collectors
	D 3771	Specification for Rubber Seals Used in Concentrating Solar Collectors
	D 3832	Specification for Rubber Contacting Liquids in Solar Energy Systems
	D 3903	Standard Specification for Rubber Seals Used in Air-Heat Transport of Solar Energy Systems

Table 5. Federal and Military Specifications Reviewed for Applicability to Solar IPH Materials and Components

Material/ Component	Type of Specification	Designation	Title of Specification
Absorptive Materials	Federal	QQ-C-320b	Chromium Plating (Electrodeposited)
	Military	Mil-C-14538b (MR)	Chromium Plating (Electrodeposited)
Flex Hoses	Military	Mil-H-19034a	Hose, Metal, Flexible
Reflective Surfaces	Federal	DD-M-00411b	Mirrors, Glass
	Federal	GGG-M-350a	Mirrors, Inspection

subjected to the degradative effects of elevated temperatures, temperature cycling, ultraviolet radiation, and moisture. Test procedures for evaluating the resistance of absorptive materials to aging should include these factors. In particular, absorptive coatings for line-focus collectors may experience operating temperatures in excess of 288°C (550°F). A recent report summarizing studies on black chrome indicated that some of these selective coatings may have questionable stability, even at temperatures as low as 200°C (392°F) [33]. Stagnation conditions encountered by evacuated-tube collectors may subject absorptive coatings in these systems to temperatures as high as 371°C (700°F), but in the absence of air. With regard to black chrome selective coatings, it is noted that the control of the electroplating process is important to the performance of the coatings [34]. An assessment of solar-related standards for absorptive materials for use in IPH systems is summarized as follows:

- ASTM Standard Practice E 744 has been prepared for the evaluation of absorptive materials for thermal applications (table 4). The standard practice stipulates exposure of the absorptive materials to the primary factors considered to cause degradation: solar radiation, elevated temperatures, temperature cycles, and moisture. The practice is applicable to flat-plate and concentrating collectors having a concentration ratio not greater than 5. The concentration ratio of line-focus collectors in IPH systems normally exceeds 5. As given in the scope of the standard, the practice is not intended for evacuated-tube collectors. A heat aging test is included in the practice whereby the test specimen is to be exposed for a period of 500 hours to the stagnation temperature expected in service. This test may be applicable to the higher temperature IPH systems, although laboratory data are needed to demonstrate the applicability.

- The performance of absorptive materials for flat-plate collectors with cover plates under conditions of collector stagnation may be evaluated according to ASTM E 781. In this test, the absorptive material specimen is exposed outdoors in a sealed insulated box with a transparent cover plate so as to simulate a flat-plate collector under stagnation. The maximum nonoperational stagnation temperature for this test is approximately 200°C (392°F). Thus, by its very nature, the test is not applicable to evaluate absorptive materials used in evacuated-tube collectors or on receivers of line-focus collectors where specimen configurations are different and operation and/or stagnation temperatures may be higher. Moreover, the coatings in evacuated-tube collectors operate in a vacuum.

- Federal specification, QQ-C-320B, and military specification, Mil-C-14538b (MR) (table 6) are available for the plating of black chrome primarily on steel or nickel-plated steel, although other metal substrates may be used. These specifications were not prepared to be applicable to IPH solar technology. Requirements for the measurement of the optical properties (i.e., absorptance and emittance) are not included in either specification. In addition, aging tests to evaluate the effects of ultraviolet radiation, temperature, and moisture on the plated specimens are not included in either specification. The federal specification requires adhesion testing of the plated chrome.

4.1.2 Needs Concerning Standards Development

The needs concerning standards development for absorptive materials for solar IPH systems are as follows:

- Standard methods of test for evaluating aging at maximum expected operating and/or stagnation temperatures for line-focus and evacuated-tube collectors should be developed. The role of other prime aging factors such as temperature cycling, ultraviolet radiation, and moisture should be considered in the test development. Moisture is not expected to play a role in the aging of a coating in a sealed evacuated tube. Previously developed test methods, (ASTM E 744 and E 781) for evaluating absorptive materials for use in low temperature applications may provide a framework for the test methods development. Current research on selective coatings for high temperature applications should aid in providing technical basis for standards development.

4.2 ABSORBER PANELS

4.2.1 Assessment

Absorber panels, which may consist of metals or polymeric materials, are components of flat-plate collectors which receive the incident solar radiation and transfer the absorbed energy to the heat transfer fluid. The panels consist of sheets which may function as or provide the support for the absorptive material. In addition, the sheets contain integral or attached tubes and headers, and inlets and outlets for connection to the fluid transport system. As part of the flat-plate collector, an absorber panel provides two main functions: it acts as an absorber material and as a containment material. Thus, in assessing the long-term performance of an absorber panel with regard to resistance to aging effects, it should be evaluated using standard practices for absorber materials (section 4.1) and for containment materials (section 4.3). Proper design of absorber panels is also necessary to achieve satisfactory long-term performance. Factors to consider during design should include materials compatibility, dimensional stability during temperature cycling, and the coefficients of linear thermal expansion of component materials. The following is an assessment of solar-related standards for absorber panels:

- ASTM standard specification B 638 (table 4) is available for copper and copper-alloy absorber panels. This specification does not contain requirements for evaluating the resistance of the panels to aging.

- ASTM standard specifications are not available for absorber panels constructed from other materials such as aluminum and polymers.

4.2.2 Needs Concerning Standards Development

The needs concerning standards development for absorber panels for solar IPH systems are as follows:

- Since the long-term performance of absorber panels may be evaluated using standard practices for absorptive materials (section 4.1) and containment materials (section 4.3), no recommendation for development of a specific materials-related standard is given at this time. It is considered important that guidelines be readily available to solar designers in order to assist in the proper design of absorber panels.

4.3 CONTAINMENT MATERIALS

4.3.1 Assessment

Containment materials may consist of glass, metals, plastics, and rubbers, although the high temperature applications of IPH solar technology are generally limited to the use of metallic or glass containment materials. Test methods for glass, metals, plastics, and rubbers are listed in appendix tables B.3, B.5, B.6, and B.7, respectively. The applicability of the test procedures to the evaluation of solar materials and components has been given [5]. The key concern in evaluating containment materials is the effect of high temperatures and of heat transfer fluids on the long-term serviceability of the materials. Containment materials should be thermally stable at anticipated operating and stagnation temperatures, and compatible with the heat transfer fluid. The following is an assessment of solar-related standards for containment materials for IPH systems:

- ASTM has issued standard practice E 712 (table 4) which describes several laboratory procedures for evaluating the corrosion performance of metallic containment materials under conditions similar to those that may occur in solar heating and cooling systems. The practice incorporates six tests:

  Practice A - Basic Immersion Test at Atmospheric Pressure
  Practice B - Heat-Rejecting Surface Test at Atmospheric Pressure
  Practice C - High-Pressure Test
  Practice D - Repeated Dip Dry Test at Atmoshpheric Pressure
  Practice E - Crevice Test at Atmospheric Pressure
  Practice F - Tube Loop Test at Atmospheric Pressure

  Although designed for evaluation of metallic components for solar heating and cooling systems, these six procedures are considered applicable to IPH systems operating at relatively low temperatures. Test temperatures for evaluation in these practices may be selected on the basis of service temperatures. With the exception of Practice C, the heating tests are conducted using test apparatus open to atmospheric pressure. These test procedures (A, B, D, E, and F) are not relevent to high temperature IPH systems where the heat transfer fluid may operate in a closed system above its normal boiling point or under a nitrogen atmosphere. Practice C, the high-pressure test, will allow screening of metallic containment materials at high pressures and temperatures and may be applicable to high temperature IPH systems. The procedure involves placement of the metal specimen and selected heat transfer fluid in an autoclave or similar test apparatus. The test may be conducted at any selected pressures, temperatures, and times. Pressures and temperatures may be selected on the basis of anticipated

service conditions. A data base on the performance of IPH solar components subjected to Practice C exposures would be useful, since data on testing IPH solar components by this practice are not available.

- ASTM standard practice E 745 (table 4) provides test procedures simulating field service for evaluating the performance under corrosive conditions of metallic containment materials in solar heating and cooling systems. Three tests are included in the practice:

  Practice A - Laboratory Exposure Test of Coupon Specimens
  Practice B - Laboratory Exposure Test of Components or Subcomponents
  Practice C - Field Exposure Test of Components or Subcomponents

  Practice A uses coupon test specimens and provides laboratory simulation of various solar system operating conditions. Practice B utilizes a component or simulated subcomponent for the test specimen, and also provides a laboratory simulation of various operating conditions. Practice C uses a component or simulated subcomponent as a test specimen, and provides field simulation of various operating conditions. The three test procedures involve heating the test specimen with the heat transfer fluid to determine the effects of temperature and fluid on the corrosion of the metal. Any fluid and any metal may be used in the test. Although standard practice E 745 was developed for evaluating metal containment materials used in solar heating and cooling systems, it may have applicability to IPH systems. The test conditions (for example, maximum temperature, temperature cycles, periods of stagnation) are not specified, but are selected on the basis of anticipated operating conditions. Procedure A, the Laboratory Test, may be conducted with the use of an autoclave to simulate systems operating under pressure above the fluid boiling point. A data base indicating the performance of IPH metal containment materials according to this practice would be useful, since the practice was developed for heating and cooling systems operating at lower temperatures than normally encountered in many IPH systems.

- Criteria for the evaluation of rubber hoses used to convey liquids in solar energy systems are provided in ASTM standard specification D 3952 (table 4). Within the specification, rubber hoses are typed according to the intended use in cold or warm climates. Three classes of rubber hose are defined depending upon the intended use with different heat transfer fluids: class A with aqueous fluids operating at or below 100°C (212°F); class AT with aqueous fluids above 100°C (212°F); and class N with nonaqueous fluids. This standard specification may have limited applicability to IPH systems. Among the requirements in the standard, tests are to be conducted to determine the resistance of the rubber hose to heating, and to the heat transfer fluid while heated. The heating tests are performed at 100°C (212°F) for class A hoses, and at temperatures selected according to those anticipated in service for class AT and class N hoses. In this latter case, the maximum temperature is 250°C (482°F). With regard to the heat transfer fluid resistance test, only class N rubber hoses are evaluated at temperatures depending upon those anticipated in service. Both class A and AT are tested at 100°C (212°F). The specification is considered inadequate for IPH systems (which may operate higher than 100°C or 212°F) in that the heat transfer fluid resistance of

class AT hoses is not tested at anticipated service temperatures. However, activities have been undertaken by ASTM to revise the specification to include a heat transfer fluid resistance test above 100°C (212°F) for class AT hoses.

- A standard practice for laboratory screening of polymeric containment materials used in solar heating and cooling systems is under consideration at ASTM. Such a practice may have applicability to those IPH systems operating at relatively low temperatures. It is of course expected that polymeric containment materials would have limited use in IPH systems because of high temperature requirements.

4.3.2 Needs Concerning Standards Development

The needs concerning standards development for containment materials in solar IPH systems are as follows:

- A data base to determine the applicability of ASTM standard practices E 712 and E 745 to IPH systems should be developed. If found applicable, these practices should be revised as necessary to indicate that IPH components operating at temperatures higher than those encountered in heating and cooling systems may be evaluated using the practices. If laboratory and field testing indicate that E 712 and E 745 are not applicable, then standard practices specific to IPH systems should be developed.

- Standard practices for screening and simulated service testing of polymeric containment materials for use in IPH systems should be developed.

4.4 COVERS/JACKETS

4.4.1 Assessment

Flat-plate solar collectors contain cover plates which may consist of glass or plastic materials, while line-focus collectors generally have glass jackets on the receivers. The covers and jackets protect the absorber and receiver, respectively, against the effects of weather and convective and radiative heat losses. Evacuated-tube collectors normally do not have covers, unless installed for a particular reason such as the prevention of tube breakage from vandalism. Transmittance and impact resistance are key properties for both glass and plastic covers, and glass jackets. In addition, abrasion resistance and embrittlement and warping are important to plastic covers. Both glass covers and jackets may be subject to breakage, if the collector design does not allow for sufficient expansion of the glass components upon heating. Test methods for glass and plastic materials are given in appendix tables B.3 and B.6, respectively. The applicability of these tests to solar technology has been previously presented [5]. An assessment of solar-related standards for covers and jackets for use in IPH systems is given as follows:

- ASTM standard practice E 765 (table 4) has been prepared for the evaluation of flat-plate cover materials. Test methods are included for measurements of transmittance, dimensional stability, impact resistance, tensile strength,

and the effect of dirt retention on solar transmittance. Aging procedures consider the effects of exposure to heat, natural weathering, and accelerated weathering. Exposure of cover materials to natural weathering under conditions simulating modes of collector operation at approximate operating temperatures may be conducted according to ASTM standard practice E 782 (table 4). According to the method in the practice, a metal box containing the cover material and an inner black surface to simulate a flat-plate collector is exposed outdoors. Practice E 782 is not intended for cover materials for evacuated-tube collectors. These two standard practices (E 765 and E 782) are applicable only to IPH systems having flat-plate collectors.

o A test method is under draft by ASTM for the effect of outgassing on cover material transmittance. Such a test would be useful to evaluate line-focus receiver assemblies having glass covers, insulation, and seals. The test procedure should allow for evaluation of outgassing at maximum anticipated exposure conditions, which in the case of a line-focus collector may exceed 288°C (550°F).

o ASTM has under consideration practices for the hail resistance and the thermal shock resistance of flat-plate collectors. The latter practice is intended to determine the ability of the collector to withstand thermal shock such as caused by precipitation. Hail damage and thermal shock to line-focus receiver jackets is considered less likely to occur than in the case of flat-plate collector covers, and such test methods may have low priority for line-focus systems. Line-focus, parabolic trough collectors are generally designed to stow when not receiving solar energy. If the line-focus system design is such that the collectors will not stow rapidly enough at the beginning of a rain or hail storm to protect the jackets, or will remain upright due to power failure, then test methods for determining hail resistance and thermal shock resistance of receiver jackets should be developed. It is interesting to note that one literature reference indicated that some glass jackets on line-focus collectors survived 19 mm (3/4 in.) hail without damage [35]. Further details were not given and in particular it was not mentioned whether the collectors were designed to stow during the hail storm.

4.4.2 Needs Concerning Standards Development

The needs concerning standards development for covers and jackets for solar IPH systems are as follows:

o A standard method of test to evaluate the effect of outgassing on the transmittance of glass covers of insulated, sealed line-focus receiver assemblies should be developed.

o The development of a hail resistance test and a thermal shock resistance test for line-focus collectors is desirable, since the collectors may not stow rapidly enough during storms to be protected.

4.5 DRIVE SYSTEMS

4.5.1 Assessment

The drive systems on line-focus tracking collectors consist of motors, drive train and gear boxes whose purpose is to maintain the focus of solar radiation on the receiver tubes. The drive system should allow the operation of the collectors with precision and accuracy up to the maximum design wind loads at which the collectors will continue to track. When the maximum design wind load is exceeded, the collectors are normally designed to stow. At least one solar designer has indicated that this concept should be evaluated to determine whether the stow position, or some other position (for example, parabolic trough back to the wind), is the most suitable collector orientation during periods of high winds. Selecting proper motors and gear boxes, with consideration to starting and stopping inertia as well as frictional and flexural loads, is also of importance to the performance of tracking collectors. An assessment of solar-related standards for drive systems used in IPH systems is summarized as follows:

- Solar-related standards for drive systems are not available.

4.5.2 Needs Concerning Standards Development

The needs concerning standards development for drive systems for line-focus solar systems are as follows:

- Since a drive system is an engineered component of the solar IPH system, no recommendation for development of a materials-related standard is given at this time. It is considered useful that guidelines be readily available to solar designers in order to assist in the proper selection of drive systems to help prevent recurrence of past failures such as those experienced in the field test program (see section 2.5). One solar designer has recommended that drive systems consist of standard components so that replacement parts may be readily obtained and installed whenever necessary. It is also considered important that the drive system be controlled in such a manner as to defocus the collectors in case of low flow of heat transfer fluids or power failures.

4.6 EVACUATED TUBES

4.6.1 Assessment

Evacuated-tube collectors are used in IPH solar systems for heat processes up to about 177°C (350°F) (table 1). Evacuated tubes consist of glass and have absorptive coatings within the evacuated interior. Test methods for coatings and glass are given in tables B.1 and B.3, respectively. Key concerns with evacuated-tube collectors are impact resistance, resistances to stresses such as thermal shock from cold filling and water hammer, and the resistance to shattering due to defects such as scratches in the glass. Another concern with evacuated tubes is the effect of the high stagnation temperatures, about 370°C (700°C), on metal components such as heat exchange fins around which the

evacuated tube is placed. An assessment of solar-related standards for evacuated tubes for use in IPH solar systems is summarized as follows:

- A standard practice for the evaluation of evacuated tube collectors under conditions simulating service temperatures is not available.

- ASTM standard practice E 823 for exposing a solar collector assembly in a non-operating mode is applicable to evaluating evacuated-tube collectors under stagnation conditions. In conducting this practice, metal components such as heat transfer fins around which the evacuated tubes are placed, if normally present in the system, should be included in the test.

- ASTM has under consideration a test method for determining the emittance of evacuated-tube collectors.

4.6.2 Needs Concerning Standards Development

The needs concerning standards development for evacuated tubes for solar IPH systems should focus on the following:

- A standard practice for the evaluation of evacuated-tube collectors under conditions simulating service should be developed. Primary factors affecting performance, such as impact resistance, thermal shock, and the permanency of the vacuum over time should be included in the practice.

4.7 FLEX HOSES/SWIVEL JOINTS

4.7.1 Assessment

Flex hoses and swivel joints are flexible couplings or movable connections in parabolic trough line-focus collectors joining the receiver tubes and piping headers. These components allow movement of the receiver tubes during collector tracking while being connected to the stationary piping headers.

Flex hoses and swivel joints normally consist of metals, although flex hoses for low temperature systems may be polymeric (rubber). Swivel joints may contain rubber seals. Test methods for metals and rubbers are given in appendix tables B.5, and B.7, respectively. The applicability of these methods to the testing of solar materials has been discussed [5]. The key properties for flex hoses and swivel joints are their resistance to high temperatures and high pressures, and compatibility with heat transfer fluids under elevated temperature and pressure, and resistance to cyclic or fatigue stress under operating conditions. Evaluative test procedures should include these factors.

A summary of the assessment of solar-related standards for flex hoses and swivel joints is as follows:

- Although flex hoses and swivel joints are classified as containment materials, the standards E 712 and E 745 for metal containment materials (see section 4.2) are not considered applicable to these components. These two ASTM standards do not include the effect of cyclic or fatigue stress which is a

primary factor affecting the long-term performance of flex hoses and swivel joints. Similarly, ASTM standard specification D 3952 (table 4) for rubber hoses used in solar energy systems is not considered applicable to flex hoses because a cyclic or fatigue stress test is not included.

- A military specification, Mil-H-19034A, is available for metallic flex hoses (table 5). This military specification is applicable only to flex hoses used on air intake and exhaust lines of engines. The specification was not developed for flexible hoses through which hot fluids are circulated under pressure. The specification has no applicability to solar technology.

4.7.2 Needs Concerning Standards Development

The needs concerning standards development for flex hoses and swivel joints used in line-focus collectors are as follows:

- A standard practice for evaluating the performance of metallic flex hoses and swivel joints under simulated service conditions should be developed. The practice should include factors affecting degradation such as high temperature, high pressure, fluid compatibility, and cyclic or fatigue stress. Results of current studies on flex hose performance may provide in part the technical basis for the standards development. In addition ASTM standard practices for containment materials may also provide a framework for the standards development.

- A standard practice for the evaluation of polymeric flex hoses under simulated service conditions would also be useful. This practice should also include the key factors which affect degradation of the flex hose, including cyclic or fatigue fatigue stress. ASTM standard specification D 3952 may provide a framework for the standards development.

4.8 FLUIDS

4.8.1 Assessment

Depending upon the maximum service temperature, a number of heat transfer fluids are available for IPH systems including water, glycols, hydrocarbons, and silicones. Fluid properties may be measured according to tests given in table appendix B.2. The key properties of transport fluids have been described [36] and include density, coefficient of thermal expansion, latent heat of vaporization, heat transfer (thermal conductivity and heat capacity), flow over a wide temperature range (viscosity), and safety (flash point, autoignition temperature, toxicity). Heat transfer fluids should be stable at the elevated temperatures encountered in IPH systems and compatible with other materials (metals, rubbers) with which they may come into contact at the elevated temperatures. An assessment of solar-related standards for heat transfer fluids for use in IPH systems is follows:

- Standard practices for evaluating heat transfer fluids under simulated service conditions are not available. In general, the development of such practices has not begun, although the ASTM has under consideration a prac-

tice for testing, at normal operating and stagnation temperature conditions, the stability of heat transfer liquids used as aqueous solutions.

- A standard practice for evaluating heat transfer fluids in service is not available and would be useful. The practice would be intended to provide data as to whether or not a fluid in service should be replaced. Some manufacturers recommend periodic measurement of values of fluid performance properties (for example, pH of aqueous glycols) after a given length of service. The standard practice for evaluating a fluid in service should include requirements as to which performance properties should be periodically determined, when they should be determined, and by which test procedures.

4.8.2 Needs Concerning Standards Development

The needs for standards development for heat transfer fluids for solar IPH systems are as follows:

- Standard specifications for the various types of heat transfer fluids except air and water for use in IPH systems should be developed. Specifications should include measurement of key properties previously listed. Standard methods of test for evaluating the thermal stability of heat transfer fluids and the effect of other materials such as metals and rubber on the fluid stability under simulated service conditions are also needed.

- A standard practice for evaluating heat transfer fluids in service should be developed.

4.9 INSULATION (THERMAL)

4.9.1 Assessment

Thermal insulations are used to reduce heat losses from solar system components such as absorbers of flat-plate systems, receivers of line-focus systems, piping, valves, and storage tanks. Thermal conductivity is the property of the material which indicates its ability to provide resistance to heat flow. Other key properties of thermal insulations for IPH systems include corrosiveness, dimensional stability, hot surface performance, moisture absorption, resistance to outgassing, surface burning characteristics, and temperature stability. Test methods for insulations including thermal conductivity are given in appendix table B.4. The applicability of these test methods to solar technology has been previously reviewed [5]. Insulations used in IPH solar systems should be resistant to the adverse effects of elevated temperatures and moisture. For outdoor installations the insulation normally contains a covering or coating to provide protection against the effects of weathering. An assessment of solar-related standards for insulations for use in IPH systems is summarized as follows:

- No solar-related materials standards are available.

- A draft standard practice for evaluating thermal insulation materials for use in solar collectors is under consideration by ASTM. For such a standard to be applicable to thermal insulations for IPH systems, provisions

should be included to provide thermal aging tests at temperatures up to at least 288°C (550°F).

- A standard practice for the installation of insulation and protective covering is not available.

4.9.2 Needs Concerning Standards Development

The needs for standards development for insulations for solar IPH systems are as follows:

- A standard practice to evaluate the performance of insulations used for IPH systems at maximum anticipated operating temperatures which may reach 288°C (550°F) should be developed.

- A standard practice for the installation of insulation and protective covering should be developed for the IPH solar industry. The practice would be intended to insure that piping insulation is properly installed and sealed against the effects of weather, particularly moisture intrusion. Experience gained from other industries using insulated piping outdoors may provide in part the basis for the standard practice for installing insulation in IPH piping systems.

4.10 PUMPS

4.10.1 Assessment

The key components of pumps used for the circulation of heat transfer fluids are the seals and rotor. Selecting the proper material for the pump (bronze, stainless steel, or cast iron) depends on the properties of the heat transfer fluid. The selection of the seals is also dependent on the type of fluid and its operating temperature. An assessment of solar-related standards for pumps used in IPH systems as follows:

- No solar-related standards are available.

4.10.2 Needs Concerning Standards Development

The needs concerning standards development for pumps for solar IPH systems are as follows:

- Since a pump is an engineered component of the solar IPH system, no recommendation for development of a materials-related standard is given at this time. It is considered useful that guidelines be readily available in order to assist solar designers in the proper selection of pumps to help prevent recurrence of past failures such as those experienced in the field test program (section 2.10). It is also important that the service conditions (including type of fluid and its operating temperature) under which the pump will perform be considered at the time of selection.

4.11 RECEIVERS (LINE-FOCUS SYSTEMS)

4.11.1 Assessment

Receivers are combinations of components such as pipes, coatings, supports, and protective jackets which operate as a unit to collect the solar energy in line-focus systems. The needs for standards development for these components have been described in other subsections of the report. Proper design is important to the performance of receivers. Factors affecting receiver performance include effective heat transfer to the fluid, accomodation of linear thermal expansion, mechanical deflection, optical design, and durability. An assessment of solar-related standards for receivers for use in IPH systems is summarized as follows:

- ASTM standard practice E 823 (table 4) provides test procedures for exposing a solar collector to an outdoor or simulated outdoor environment in a non-operational mode. The outdoor exposure test is conducted for a minimum of 30 days in which, for each day, the cumulative minimum radiant exposure, measured in the plane of the collector, must be 17,000 $kJ/m^2 \cdot day$ (1500 $Btu/ft^2 \cdot day$). It is stated within the document that the practice applies to all collector types. The test specimen must be a complete collector assembly which may be equipped with self-contained, self-actuated protective devices. Thus, line-focus collectors, which are normally designed with protective devices to defocus whenever their temperature exceeds a specified limit, may be tested according to this practice. However, if a line-focus collector were to remain defocused for a significant portion of the thirty-day test period, it is conceivable that the temperature of the receiver assembly may not reach high values for periods of time long enough to cause accelerated aging of the receiver materials. It may be useful to develop an accelerated aging test which would be specific for receivers for line-focus collectors.

4.11.2 Needs Concerning Standards Development

The needs concerning standards development for receivers in line-focus solar IPH systems are as follows:

- Since the performance of components comprising receivers (e.g., absorptive or containment materials) may be evaluated according to standards developed for the specific item, no recommendation for the development of a specific materials-related standard is given at this time.

- A test procedure to evaluate a receiver assembly under accelerated exposure conditions should be developed. The procedure should incorporate the primary factors considered to affect in-service performance. Current research on the performance of receivers may provide in part the technical basis of the standards development.

- Guidelines for the proper design of receivers should be readily available to assist solar designers to help prevent recurrence of past problems such as those experienced in the field test program (section 2.11).

4.12 REFLECTIVE SURFACES

4.12.1 Assessment

Reflective surfaces are important components of IPH solar systems in that they concentrate solar radiation on the absorber in both evacuated-tube and line-focus systems. Reflective surfaces may consist of mirrored glass, polished metals, or metallized plastic film materials. Test procedures, which have been previously reviewed for their applicability to the evaluation of solar components [5], are listed in appendix tables B.3, B.5, and B.6 for glass, metals, and plastics, respectively. The primary property of a relective surface is reflectivity. Reflectivity is determined according to ASTM E 424 (table B.3). Primary factors which may effect the reflectivity of a surface are: abrasion, impact, mechanical stress, temperature cycling, and weathering including moisture, ultraviolet radiation, and atmospheric pollutants. Test methods for evaluating the resistance to aging of reflective surfaces should include the effect of these factors. In many IPH systems, reflective surfaces are adhesively bonded to substrates. The adhesive should be durable and resistance to the effects of weathering, particularly moisture, and temperature cycling. Creep is important, if sustained loads are applied to the surface. Reflective surfaces are not expected to be subjected to temperatures significantly above ambient, since they reflect solar radiation. If the surfaces become appreciably soiled, then they may absorb greater amounts of solar radiation. Reflective surfaces which become soiled are normally cleaned. Periodic cleaning should not cause significant loss of reflectivity. An assessment of solar-related standards for reflective surfaces for use in IPH systems is summarized as follows:

- Standard practices for evaluating the long-term performance of reflective surfaces under simulated and in-service exposure conditions are not available.

- Federal specifications, DD-M-00411b and GGG-M-350a, are available for glass wall mirrors and inspection mirrors, respectively (table 5). These specifications are specific to mirrors used indoors. They contain no requirements for evaluating mirrors exposed outdoors and have no applicability to solar IPH technology.

4.12.2 Needs Concerning Standards Development

The needs concerning standards development for reflective surfaces for solar IPH systems are listed as:

- Standard practices for evaluating the long-term performance of reflective surfaces should be developed. These practices should include tests to determine the resistance of the reflective surface to the primary factors affecting performance including the effect of cleaning on reflectivitiy. The research and development activities which have been conducted may provide in part the technical basis for the standards development. Development of standard evaluative test procedures should not await the completion of current research projects on reflective surfaces since the period of time to develop draft standard methods of test may be lengthy.

- A standard practice for evaluating the performance of adhesives for bonding reflective surfaces to substrates should be developed. The practice should include the effect of the primary factors which may affect adhesive degradation: moisture, temperature, temperature cycling, and stress. The standard practice may be based in part on existing test methods for adhesives. Current research concerning adhesive bonding of reflective surfaces should also aid in providing technical basis for standards development.

4.13 SEALS (RUBBER)

4.13.1 Assessment

Seals are nonrigid elastomeric materials set in joints between components to prevent air and water leakage, and dust and dirt penetration into the collector and other enclosed areas. Seals are also used to accommodate differences in thermal movement of connected system components. In addition, seals may be incorporated in the heat transfer fluid circulation system. Examples of the use of seals in IPH systems are:

- to seal a flat glass protective cover over a receiver tube,
- to seal the space between the absorber and jacket at the end of a receiver tube, and
- to seal evacuated tubes to the pipe manifold housing.

Test methods for rubber materials are given in appendix table B.7, and have been reviewed previously for their applicability to solar technology [5]. The primary factors affecting the aging of rubber seals are temperature, temperature cycling, contact with heat transfer fluids, weathering, and atmosphere pollutants. An assessment of solar-related standards for rubber seals for use in IPH systems is given as follows:

- ASTM standard specifications D 3667, D 3771, and D 3903 are available for rubber seals used in flat-plate collectors, concentrating collectors, and air-heat transport solar systems, respectively (table 4). These specifications have requirements to subject rubber seals to many of the factors considered to affect their performance including resistance to heating, ozone, and low temperatures. Test temperatures for determining heat resistance may be selected based on anticipated service conditions. None of these specifications contains a requirement to determine the ultraviolet light resistance of rubber seals receiving such exposure in service. It is stated in the specifications that the seals are to be made from rubber compounds which are impermeable to ultraviolet light. A requirement in the specifications to determine the ultraviolet resistance of seals which are exposed to sunlight in service would be useful.

- A data base is lacking to indicate the performance of rubber seals used in IPH systems when subjected to the test requirements described in the ASTM specifications D 3667, D 3771, and D 3903. Development of such a data base is needed.

- ASTM standard specification D 3832 provides the general requirements for materials used in preformed rubber seals that contact the heat transfer fluid in solar energy systems. The specification may have limited applicability to IPH systems. Requirements are included to determine the compression set of rubber seals upon heating, and to measure their resistance to heating, ozone, low temperature, and the heat transfer fluid used in service. The test for resistance to the heat transfer fluid may be conducted at temperatures selected according to the type of fluid and the anticipated maximum service temperature. However, this test procedure does not provide for evaluating the rubber seals in a pressure vessel with the heat transfer fluid at a temperature above its normal boiling point at atmospheric pressure. Thus, the specification is not considered adequate to evaluate rubber seals used in IPH collectors having pressurized heat transfer fluid systems.

4.13.2 Needs Concerning Standards Development

The needs concerning standards development for seals for solar IPH systems are given as follows:

- A test procedure to determine the ultraviolet light resistance of rubber seals exposed to sunlight in service should be developed for incorporation in ASTM standard specifications D 3667, D 3771, and D 3903.

- A data base should be developed to indicate the performance of rubber seals used for IPH systems, when subjected to the test requirements in ASTM standard specifications D 3667, D 3771, and D 3903.

- ASTM standard specification D 3832 should be revised to include a test requirement for the determination of the resistance of rubber seals to heat transfer fluids operating in pressurized systems above their normal boiling point at atmospheric pressure.

4.14 TRACKERS

4.14.1 Assessment

Trackers are used in line-focus systems to sense the position of the sun relative to the collector. The tracker activates the drive mechanism to maintain focus of the concentrated solar radiation on the receiver tube. Two types of trackers are presently in use [22]. The first incorporates two photocells separated by a shadow band. If one cell senses less light than the other, the concentrator is moved to equalize the light sensitivity incident on both cells. The concentrator is thus kept normal to the sun. The second type of tracker uses a heat flux sensor consisting of a fine wire on the receiver tube. Temperature fluctuations in the wire due to varying heat flux result in changes in the resistance of the wire to activate the drive mechanism. The key property of the tracker is its ability to track the sun's position reliably. An assessment of solar-related standards for trackers for use in IPH systems is summarized as follows:

- A solar-related standard for trackers is not available. Materials used in trackers are not exposed to outdoor conditions differing appreciably from conditions which building materials are normally exposed. The evaluation of materials used for trackers should follow normally accepted design practices for selecting materials used outdoors.

4.14.2 Needs Concerning Standards Development

The needs concerning standards development for trackers for IPH line-focus systems are as follows:

- Since a tracker is an engineered component of the solar IPH system, no recommendation for development of a materials-related standard is given at this time. It is important that trackers be designed to function reliably as intended. Guidelines should be readily available to assist solar designers in tracker selection in order to help prevent recurrence of past problems such as those experienced in the field test program (section 2.14).

4.15 TROUGHS (PARABOLIC)

4.15.1 Assessment

Parabolic troughs are important components of line-focus collector systems. The key functions of troughs have been described [22]: the trough should provide firm support and a smooth distortion-free substrate for the reflective surface; and it should provide adequate rigidity under torque to maintain collector accuracy. Materials from which troughs are generally constructed include metals, plastics, and composites such as metal skins on honeycomb cores. Tests for metals and plastics are given in appendix tables B.5 and B.6, respectively. Troughs have peripheral members such as support pilons which may be coated to protect the member against the effects of weather. In general, the troughs and protective coatings on peripheral members would be subjected to exposure conditions normally experienced by building materials, although the configuration and operation of the troughs may give rise to stress conditions not encountered by buildings. Existing aging test procedures for metals and plastics may be applicable to troughs. However, the reliability of correlating in-service performance of materials with accelerated aging tests is questionable [37]. Accelerated aging tests for troughs, incorporating the key degradation factors such as moisture, temperature, ultraviolet radiation, pollutants, and impact, and also simulating specimen configuration and operating conditions may be useful. Future troughs may consist of plastic materials having innovative designs. Traditionally, the durability of plastics has been difficult to assess using accelerated aging procedures. An assessment of solar-related standards for troughs for IPH systems is given as follows:

- No standard practice for evaluating the long-term performance for troughs under simulated-service conditions is available.

4.15.2 Needs Concerning Standards Development

The needs concerning standards development for troughs for IPH line-focus solar systems are:

- Since troughs using innovative materials and/or construction techniques are under development, a standard practice for their evaluation either under in-service or simulated-service conditions should be developed. Degradation factors incorporated in the standard practice should include: temperature, moisture, ultraviolet radiation, pollutants, and stress. In the case of sandwich panels used for troughs, the standard method of test should include evaluation of the adhesive bond between the core and the skin of the panel. Factors effecting the bond performance include moisture, temperature, stress, and temperature cycles.

5. SUMMARY AND CONCLUSIONS

This study was conducted to assess the need for standards development for materials and components of solar IPH systems. Emphasis was placed on standards to evaluate materials performance under service conditions. The assessment was based on the availability of existing standards and their applicability to IPH materials and components. A field survey of ten field test projects was conducted to observe the performance of materials in operational systems. Information from the literature and discussions with individuals in the IPH industry complemented that obtained from the field survey. From the results of the study, the following conclusions are made:

- Materials problems have occurred to some degree at each of the IPH field test project sites visited. In worst cases, materials failures have occurred resulting in inoperation of the system, or costly replacement of components. The problems have been associated with inadequate system design, or selection of materials which were not fully evaluated for the anticipated service conditions (section 2). Field observations of inadequate materials performance provide supportive evidence that evaluative test procedures are needed to assist in the selection of materials.

- Material failures and design deficiencies have been described in the literature reports (section 3) and at round table discussions at solar IPH conferences. Research and development is underway to correct problems and improve material performance and system design.

- Maximum temperatures encountered by IPH systems have at times been underestimated by designers (section 2).

- Some standard methods of test for evaluating components for solar heating and cooling systems have been developed (table 4). These methods are applicable to IPH systems employing flat-plate collectors. Some of the standard methods may be applicable to concentrating systems operating at low temperatures (section 4).

- In cases where standards developed for flat-plate collectors for heating and cooling applications may be applicable to low temperature IPH systems, data bases are lacking to demonstrate the applicability (section 4).

- Standard methods of test for evaluating the long-term performance of key components of line-focus and evacuated-tube collector systems operating at high temperatures (including low flow rates or stagnation conditions) are needed (section 4).

- Lack of standard methods of test has had an adverse effect on material procurement by solar architects-engineers (section 3). Materials are often selected according to availability, manufacturers' specifications, or brand name without evaluation of long-term performance according to standardized test procedures which consider the in-service conditions of use.

6. RECOMMENDATIONS

As concluded in section 5, standard methods of test are needed to evaluate long-term performance of IPH materials and components. The test methods should incorporate the primary factors effecting degradation of the materials, and exposure conditions should be based upon anticipated service conditions. The exposure of materials to high temperatures and high pressures experienced in concentrating collector systems is of particular importance. It is equally important that reflective surfaces be durable and maintain their reflectivity. In section 4, the needs for standards development were identified for individual IPH materials and components. These needs are summarized in table 6.

It is recommended that standards be developed for those components, as outlined in table 6. The development of the standards should draw on the experience gained from current research studies on materials and component performance (section 3). In cases where laboratory test data are lacking or considered to be insufficient to support standards development, laboratory studies should be initiated to provide a data base. Accelerated aging tests incorporated in standards should be based upon laboratory data which may be related to the performance of materials in service, as observed from field studies of operational systems.

The availability of standards for the solar IPH industry could be beneficial in a number of ways. First, the solar IPH industry is in the early stages of development and premature material failures have occurred in many of the field test installations. Standards for materials evaluation during system development would assist in preventing the recurrence of in-service failures. The standards may be based in part on the experiences gained in the IPH field tests. Second, standards provide means for evaluating innovative materials used as replacement for conventional materials in future IPH installations. Thirdly, standards availability would contribute to the commercialization of a developing industry. Standards would instill user confidence that selected materials and components have been satisfactorily evaluated for long-term performance.

A priority for the needs for standards development has been assigned to each component, as given in table 7. Priority ratings assigned to each component are high, medium, and low. The priorities relate to the importance of having available standards for evaluating the in-service performance of each component. Criteria for assigning priorities are similar to those previously developed by Skoda and Masters [5] and are as follows:

- The importance of the component to the performance of the system.
- The availability of existing standards to estimate the in-service performance of the component.
- The incidence of problems observed for the component during the field survey.
- The potential for developing useful consensus standards for the component.

Table 6. Summary of Needs for Materials-Related Standards Development for IPH Components and the Priority of the Need

Component	Needs for Materials-Related Standards Development	Priority
Absorptive Coatings	o Standard practice for evaluating aging at maximum conditions expected in service for line-focus and evacuated-tube collectors	High
Containment Materials (Metallic)	o Evaluate the applicability of ASTM standard practices E 712 and E 745 to metallic containment materials at high temperatures experienced in IPH systems	High
Containment Materials (Polymeric)	o Standard practices for screening and simulated service testing of polymeric containment materials	High
Evacuated Tubes	o Standard practice for the evaluation of evacuated tubes under conditions simulating those expected in service	High
Flex Hoses/Swivel Joints (Metallic and Polymeric)	o Standard practices for evaluation of metallic and polymeric flex hoses and swivel joints under conditions simulating those expected in service	High
Fluids	o Standard methods of test for the stability of IPH heat transfer fluids under conditions expected in service	High
	o Standard practice for determining changes in properties of heat transfer fluids under conditions expected in service	High
Insulation	o Standard practice for the installation of insulation and protective covering on heat transfer fluid pipes and related accessories	High
Reflective Surfaces	o Standard practice for evaluating reflective surfaces of concentrating collectors under anticipted service and environmental conditions	High
	o Standard practice for evaluating adhesives for reflective surfaces for line-focus collector systems	High
	o Standard practice for cleaning reflective surfaces	High
Seals (Rubber)	o Revision of ASTM standard specification D 3832 for applicability to seals used in pressurized IPH systems	High
Covers/Jackets	o Standard method of test to evaluate the effect of out-gassing on the transmittance of glass covers of insulated, sealed receiver assemblies	Medium
Fluids	o Standard specifications for the various types of heat transfer fluids used in IPH collector systems	Medium
Insulation (Thermal)	o Standard practice to evaluate insulations under conditions simulating those expected in service	Medium
Seals (Rubber)	o Method of test to determine the ultraviolet light resistance of seals exposed to sunlight in service	Medium
	o Development of a data base to determine the applicability of ASTM standard specifications D 3667, D 3771, and D 3903 to seals used in IPH systems	Medium
Troughs (Parabolic)	o Standard practice for the evaluation of troughs for line-focus collectors under simulated and service conditions	Medium
Covers/Jackets	o Standard practices for the determination of hail resistance and thermal shock resistance of jackets for line-focus collectors	Low

The development of standards for materials and component evaluation may be a rather lengthy process. In the meantime, solar designers need to select materials for construction of IPH systems. In the absence of standards for evaluating materials, the solar designer should carefully consider the selection of materials. Experience gained from the IPH field test projects as to which components have performed satisfactorily may be useful for materials selection but is limited. The IPH field test projects have been operational for only short lengths of time. Guidelines to aid in the selection of materials for use in solar energy systems have been presented [5, 7]. These guidelines provide a valuable framework of the factors to be considered in the materials selection process, and should be consulted by the solar designer considering the use of untried materials.

7. REFERENCES

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APPENDIX A. SUMMARY OF THE IPH FIELD TEST INSTALLATIONS VISITED

Ten IPH field test installations were visited during the study to observe the performance of materials under operational conditions. This appendix presents a summary description of the solar system and industrial application at each site. The summary descriptions presented in the following pages are based in part on information by Kutscher [A1] and Shingleton [A2].

REFERENCES FOR APPENDIX A

A1. Design Considerations for Solar Industrial Process Heat Systems, Kutscher, Charles F., Editor, Solar Energy Research Institute, SERI/TP-632-783, 54 pages (March 1981).

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A.1 SITE NO. 1 IPH SYSTEM

The industrial process at site no. 1 uses both hot water and steam to wash cans in its Sacramento, California, soup canning plant. Solar energy first contributed hot water at 66°C (150°F) to this process in June of 1978. This solar energy system was one of the first solar industrial process heat systems in the field test program to begin operation.

The system has both flat-plate and line-focus collectors. Filtered well water flows through the flat-plate array under plant water pressure. Flat-plate collectors are used in an array of 414 m^2 (4,455 ft^2) net area. The collectors are mounted on an existing plant roof at an angle of 25° with due south orientation. The flat-plate collectors preheat water before entry to the array of concentrating collectors. Six groups of parabolic trough concentrators are connected in parallel. Each group has eight collectors in series. The trough axis is east/west and the concentrator array area is 268 m^2 (2,880 ft^2). This is a one-pass system with no return piping to the collectors from storage. Solar heated water is stored in a 64,900 L (17,150 gal) tank. Upon demand, water is pumped through a steam heat exchanger to the can washing process.

- COLLECTOR TYPE: Liquid flat-plate and tracking, parabolic trough concentrator
- APPLICATION: Can washing
- SITE SPECIFIC FEATURE: Roof-mounted collector array
- STORAGE: Hot water tank
- FREEZE PROTECTION: Recirculation

A.2 SITE NO. 2 IPH SYSTEM

The textile plant at site no. 2 is located in LaFrance, South Carolina. Solar energy is utilized in a 132°C (270°F) maximum temperature water/glycol loop which produces 88°C (190°F) water for use in a dye beck. A dye beck is a special vat in the batch process dyeing operations of a textile plant. The solar energy system is ground mounted and retrofitted to the existing process equipment.

The system utilizes 396 evacuated-tube collectors which provide a net area of 621 m^2 (5,680 ft^2). The collectors are arranged in 11 rows having 36 collectors.

The solar storage tank and pumps are located in a protected outside area. The controller and data acquisition systems are located in a separate room in the plant adapted for that purpose.

- COLLECTOR TYPE: Evacuated tube
- APPLICATION: Textile dyeing
- SITE SPECIFIC FEATURE: Ground-mounted collector array
- STORAGE TYPE: Water
- FREEZE PROTECTION: Ethylene glycol

A.3 SITE NO. 3 IPH SYSTEM

Solar energy is utilized in a low temperature water loop which produces hot water used in the concrete block curing process. The concrete block plant at site no. 2 is located in Middletown, Pennsylvania. The solar energy system was installed from May 1978 to August 1978 at the time the plant was constructed.

The system utilizes 135 line-focus concentrating collectors which provide an effective area of 856 m^2 (9,216 ft^2). The collectors are single-axis tracking, with tracking provided by 0.3 m (1 ft) wide mirror strips, mounted in parallel rows on the 15° sloped roof of the building. The collectors have a 24:1 concentration ratio with an a stationary steel tube receiver without a glass cover at their focus. They are mounted on an east-west axis with altitude tracking. One tracking motor is provided for every vertical row of collectors.

The collectors are arranged in 5 horizontal rows with 7 collector modules per row. The absorbers are five 76 m (250 ft) continuous steel pipes that are piped in parallel. The absorbers are piped through flexible hoses to the system supply and return piping.

The solar system is designed to provide 57°C (200°F) water/glycol solution to a heat exchanger located in the boiler room of the plant. At the heat exchanger, water is supplied to the rotoclave for the curing process. The only storage is in the rotoclave. All of the mechanical equipment for the solar system is enclosed in the boiler room except the solar rotoclave pump.

- COLLECTOR TYPE: Tracking mirror, fixed-receiver concentrator
- APPLICATION: Curing of concrete blocks
- SITE SPECIFIC FEATURE: Roof-mounted collector array
- STORAGE TYPE: Storage provided by process rotoclave
- FREEZE PROTECTION: 50/50 solution of water and ethylene glycol

A.4 SITE NO. 4 IPH SYSTEM

The site no. 4 IPH system is constructed at a food processing plant in Gilroy, California which dehydrates onions and garlic. The collector array, designed to provide 99°C (210°F) water, consists of evacuated-tube modules with an aperture area of 553 m^2 (5,950 ft^2). The collector bank is supported by wooden trusses built on a low-sloped warehouse roof. The existing roof required minor modification for collector installation. The collector array location was some distance from the process heat exchanger, which necessitated long expanses of pipe to transport the collected energy to the dehydrator. The array is oriented due south at a tilt of 22° off horizontal. This tilt angle maximizes energy collected during the peak drying season.

Water is passed through the collector modules in parallel and supplied to one of two continuous-operation belt dehydrators. A liquid-to-air heat exchanger delivers solar energy to the drying air stream. An in-line natural gas burner then heats the air to operating temperature. The outlet water from the heat exchanger is pumped back to the collector array. Storage is not provided in the system. When heat is not required by the primary process, the solar energy is used to preheat the feed water for the plant steam boiler.

- COLLECTOR TYPE: Evacuated tube
- APPLICATION: Dehydration of onions and garlic
- SITE SPECIFIC FEATURES: Roof-mounted collector array
- STORAGE: None
- FREEZE PROTECTION: Recirculation

A.5 SITE NO. 5 IPH SYSTEM

The solar IPH system at site no. 5 is used to dry fruit, chiefly grapes, at a Fresno, California location. In August 1978, solar energy was first utilized in one of twelve dehydration process lines.

The collector array has an aperture area of 1,951 m^2 (21,000 ft^2), oriented due south and tilted 36° of horizontal. The 30 panels of the array measure 1.2 m (4 ft) x 55 m (180 ft) and are connected in parallel. The supply duct size balances the flow in each collector panel. Duct runs are relatively short and take a direct route to and from equipment, although a driveway at the plant had to be spanned overhead. Solar-heated air at the design temperature of 63°C (145°F) is blown to the drying process, to storage, or both. The solar-heated air may reach temperatures in the collectors greater than 93°C (200°F). When necessary, ambient air is mixed with the solar-heated air to achieve process temperatures. Natural gas burners in the drying tunnel also augment the solar-heated air to operating temperatures whenever necessary. Exhaust air is vented through the heat recovery wheel, which in turn, warms the ambient make-up air. The storage consists of a 396 m^3 (14,000 ft^3) bin filled with rocks. It is constructed on grade and supplies heat during the second work shift at the plant. The interior of the bin and exterior of the ducts are insulated with spray-in-place polyurethane foam.

- COLLECTOR TYPE: Air flat-plate
- APPLICATION: Dehydration of fruit (grapes and plums)
- SITE SPECIFIC FEATURES: Heat recovery wheel, site built, ground-mounted collector array
- STORAGE: Rock bin
- FREEZE PROTECTION: None required

A.6 SITE NO. 6 IPH SYSTEM

The site no. 6 IPH system is located in Pasadena, California. The 603 m^2 (6,496 ft^2) array contains 406 solar collectors, each 0.6 m (2 ft) x 2.4 m (8 ft). The parabolic trough reflectors are oriented north/south with azimuth tracking. A stationary, selective coated absorber pipe is encapsulated in a glass jacket. The entire array rests on a space frame which spans the existing laundry roof.

In normal operational mode, water is circulated in a closed loop through the collector array and then through U-tubes in a kettle type boiler to generate saturated steam at 0.72 MPa (105 lb/in.^{2}). The outlet water temperature of the collector array must exceed the boiler shellside water temperature by a minimum of 5.5°C (10°F) before flow through the boiler tubes is permitted. The concept of thermal storage at this plant has been abandoned. If there is no demand for steam, the power to the sun-tracking device will be turned off automatically when the collector outlet temperature exceeds a limit of 199°C (390°F). The tracker power is restored when the circulating water temperature drops to 199°C (390°F).

Volumetric changes in the fluid are accommodated by an expansion tank and the loop pressure (1.72 MPa or 250 lb/in.^{2}) is maintained by nitrogen blanket in that tank.

Since this array is located in southern California, no freeze protection mode has been designed into this system.

- COLLECTOR TYPE: Tracking parabolic trough concentrators
- APPLICATION: Steam generation for commercial laundry
- SITE SPECIFIC FEATURE: Space frame which supports the collectors bridges the entire laundry building
- STORAGE: None
- FREEZE PROTECTION: None

A.7 SITE NO. 7 IPH SYSTEM

The IPH system at site no. 7 supplies steam for a gauze bleaching process. The system, located at Sherman, Texas, has been in operation since January 1980.

Parabolic trough concentrators are used to generate the steam. The collectors are arranged in four parallel loops with 48 reflectors in each loop, totaling 1,070 m^2 (11,520 ft^2) of aperture area. The array is ground-mounted and has an orientation northeast/southwest to align with the plant building. For aesthetic reasons, the entire array was constructed in an shallow pit below the surrounding natural terrain.

In normal operation, high temperature and pressure water is stored in the 189,250 L (50,000 gal) flash boiler. A 25 horespower pump circulates the water through the collector array at 3.8 L/s (60 gal/min). When the solar-heated water from the collectors is hot enough, it flashes to steam after passing through a throttling valve in a flash boiler. This steam is applied directly to the plant's steam main. Freeze protection is accomplished by circulating boiler water in a reverse flow at a reduced rate through the collectors. The throttling valve is bypassed in this mode.

- COLLECTOR TYPE: Tracking parabolic trough concentrators
- APPLICATION: Gauze bleaching
- SITE SPECIFIC FEATURE: Ground-mounted collector array
- STORAGE: Flash boiler
- FREEZE PROTECTION: Recirculation

A.8 SITE NO. 8 IPH SYSTEM

Solar energy is collected in a high temperature water loop that feeds a steam generator to provide steam to an orange juice pasteurizing process. The process plant for site no. 8 is located in Bradenton, Florida. The solar energy system was field erected from June of 1979 through September of 1980.

The system utilizes 336 compound parabolic concentrating (CPC) evacuated-tube collectors which provide an effective aperture area of 929 m^2 (10,000 ft^2). The concentration ratio is 3:1. The collectors are mounted on a single-axis and may be seasonally adjusted for tilt angle.

The ground-mounted collectors are arranged in 42 rows of 8 collectors, placed in 2 side-by-side arrays of 21 rows each. The collector modules are mounted in such a way that the heaters provide parallel fluid flow between each module.

The solar system is designed to provide 177°C (350°F) water at 1.03 MPa (150 lb/in.^{2}) to a steam generator located in the solar mechanical building. The steam is sent to a frozen juice block crusher when the solar system exceeds 0.69 MPa (100 lb/in.^{2}) boiler pressure. If the crusher is not operating, the steam is used for a glycol concentrator at 0.14 MPa (20 lb/in.^{2}). A third option is to send steam to preheat the water to the crusher boiler if the solar system cannot make sufficient steam when the crusher is operating.

- COLLECTOR TYPE: Seasonally adjusted, concentrator with evacuated-tube receiver
- APPLICATION: Orange juice pasteurization
- SITE SPECIFIC FEATURE: Ground-mounted collector array
- STORAGE: None
- FREEZE PROTECTION: Glycol solution

A.9 SITE NO. 9 IPH SYSTEM

Solar energy is utilized in a high temperature water loop which produces steam used in a textile drying process. The textile plant with site no. 9 is located in Fairfax, Alabama. The solar energy system was retrofitted from October 1977 through September 1978 to the existing wooden frame building.

The system utilizes concentrating parabolic trough collectors which provide an array size of 772 m^2 (8,313 ft^2). The collectors are in parallel 24 m (80 ft) rows on the low-sloped roof of the building and have a 40:1 concentration ratio. They are mounted on an east-west axis with altitude tracking. A tracking mechanism is installed on each row.

The collectors are arranged in 24 rows, each consisting of one collector erected in four 6 m (20 ft) sections. The four 6 m (20 ft) absorbers are piped in series. The 24 rows are piped in parallel. The absorbers are connected through rotary joints to the collector supply and return piping.

The solar system is designed to provide 158°C (317°F) water at 0.59 MPa (85 lb/$in.^2$) to a steam generator located in a penthouse building on the existing roof. The steam generator produces steam for the textile drying process. A pump returns the condensate to the steam generator. No storage is provided for this system. All of the mechanical equipment for the solar system is enclosed in the penthouse including pumps, steam generator, expansion tank and control equipment.

- COLLECTOR TYPE: Tracking parabolic trough concentrator
- APPLICATION: Textile drying
- SITE SPECIFIC FEATURE: Roof-mounted collector array
- STORAGE TYPE: None
- FREEZE PROTECTION: Immersion heaters and recirculation

A.10 SITE NO. 10 IPH SYSTEM

Solar energy is used to generate industrial process steam at site no. 10 located in Dalton, Georgia. In September 1978, construction began on this field-mounted system that was retrofitted to the existing process equipment and was essentially completed in January 1981.

This system utilizes 15 rows of parabolic trough collectors in a north-south orientation, with 10° tilt, facing south. The system has an area of 923 m^2 (9,930 ft^2) and is designed to provide 186°C (367°F) steam at 1.14 MPa (165 $lb/in.^2$).

The heat transfer fluid circulates through the collectors and boils water in a kettle boiler to produce steam. An accumulator tank connected to the fluid loop serves as an expansion tank and dump tank. No overnight freeze protection is required.

- COLLECTOR TYPE: Parabolic trough tracking collectors
- APPLICATION: Latex manufacturing
- SITE SPECIFIC FEATURE: Ground-mounted collector array
- STORAGE: None
- FREEZE PROTECTION: None

APPENDIX B. TEST METHODS FOR MATERIALS COMMONLY USED IN SOLAR ENERGY SYSTEMS

This appendix presents tables of test methods for materials commonly used for solar energy systems: coatings, fluids, glasses, insulation, metals, plastics, and rubbers. The test methods were originally compiled by Skoda and Masters [B1] in conjunction with their survey of materials performance of solar collector systems. The test methods have been developed by standards organizations such as ASTM (American Society for Testing and Materials), ANSI (American National Standards Institute), and ISO (International Organization for Standardization), by the Federal government (Federal and military standards and specifications), and by trade associations (industrial standards). Because many of these test methods are considered applicable to the development of standards for materials and components for solar industrial process heat systems, the tables have been reproduced here. The tables were reviewed to eliminate reference to any test methods which have been withdrawn since the original tables were published.

REFERENCE FOR APPENDIX B

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Table B.1 Existing Test Methods for Coatings

Type of Test	Test Designation
Abrasion, resistance to	ASTM D658, D968, Fed. Std. 141a
Adhesion	ASTM B571,C633, D2197, D3359, ISO 2819
Atmospheric pollutants, resistance to	ASTM B117, B287, D1543, D1654, D3129, G1, G33, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-103B, TT-C-530A, TT-C-00498A, TT-E-516A, TT-E-522A, TT-P-102D
Cleanability	ASTM C756, D2486
Color change	ASTM D1535, D1543, D1729, D2244, D2616, G45
Corrosion resistance	ASTM B117, D1014, D1654, D2933, G1, ISO 1462
Flammability	ASTM D1360, E162, E286
Flexural strength	ASTM B571, D522, D1737, Fed. Std. 141a
Fungus resistance	ASTM D3129, D3272, D3273, G21, Mil. Std. 810C, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-51D, TT-P-61E, TT-P-71E, TT-P-81E, TT-P-19C, TT-P-55B
Gloss	ASTM D523
Impact resistance	ASTM D1474, D2794, D3170, SAE J400
Moisture, resistance to	ASTM D1010, D1187, D1735, D2246, D2247, D2366, D2932, Mil. Std. 810C, Fed. Specs. TT-P-641F, TT-C-1079A
Optical properties	ASTM E97, E424, E434
Permeability	ASTM C355, D1653, E96
Physical Integrity	
checking	ASTM D660
cracking	ASTM D661
Scratch resistance	ASTM D2197
Surface uniformity	ASTM E136
Tensile strength	ASTM D522, D1737, D2370

Table B.1. (Continued)

Thermal aging, resistance to	ASTM D2246, Mil. Std. 810C
Thickness	ASTM B567, D1005, D1186, D1400, E376, ISO 2178, 2360, 2361
Weathering, resistance to	ASTM D822, D1006, D1014, D2620, G7, G23, G24, G26, Mil. Std. 810C, Fed. Std. 141a, Fed. Specs. TT-P-31D, TT-P-61E, TT-P-71E, TT-P-81E, TT-C-530A, TT-P-19C, TT-P-55B, TT-P-95B, TT-P-1181A, TT-C-00498A, TT-E-516A, TT-E-522A, TT-P-37C, TT-P-102D

Table B.2. Existing Test Methods for Fluids

Type of Test	Test Designation
Ash content	ASTM D482, D1119
Autoignition temperature	ASTM E659
Boiling point	ASTM D1120
Color	
Corrosivity	ASTM D807, D2688, D2776, D3263
Expansion coefficient	ASTM D1903
Fire point	ASTM D92
Flash point	ASTM D56
Foaming	ASTM D1881
Freezing point	ASTM D1015, D1177
pH	ASTM D1287
Reserve alkalinity	ASTM D1121
Specific gravity, density	ASTM D941, D1122
Specific heat	ASTM D2766
Thermal conductivity	ASTM D2717
Ultraviolet absorbance	ASTM D2008
Vapor pressure	ASTM D323
Viscosity	ASTM D445
Water content	ASTM D1123, D1744

Table B.3. Existing Test Methods for Glasses

Type of Test	Test Designation
Analyzing stress	ASTM F218
Annealing point, strain point	ASTM C336, C598
Atmospheric pollutants, resistance to	ASTM C724, C777, ISO 1776
Coefficient of expansion	ASTM C824, E228, E289
Creep	Fed. Spec. DD-G-1403
Density	ASTM C693, C729
Fatigue	
Flatness	ASTM C314
Flexural strength	ASTM C158
Impact strength	ANSI Z97.1, Fed. Std. 406
Indentation hardness	ASTM C730
Optical properties	ASTM E424
Softening point	ASTM C338
Thermal aging, resistance to	ANSI Z97.1
Thermal conductivity	ASTM C177, C408
Thermal shock	ASTM C149
Young's modulus, shear modulus, Poisson's ratio	ASTM C623

Table B.4. Existing Test Methods for Insulation

Type of Test	Test Designation
Atmospheric pollutants, resistance to	
Biodeterioration	ASTM D3273, G21, G22
Breaking strength	ASTM C446
Compressive strength	ASTM C165
Deflection	ASTM C209
Density	ASTM C167, C209, C302, C303, C519, C520
Dimensional stability	ASTM C548, D1042
Expansion	ASTM D1037
Flame spread	ASTM E84
Flexural strength	ASTM C203
Impact resistance (by dropping)	ASTM C487
Indentation hardness	ASTM C569
Mechanical stability	ASTM C421
Moisture absorption	ASTM C209
Moisture, resistance to	Mil. Std. 810C
Parting strength	ASTM C686
Properties at abnormal temperature	ASTM D759
Racking load	ASTM E72
Specific heat	ASTM C351
Tensile strength	ASTM C209
Thermal aging, resistance to	ASTM C356, C411, C447, D794, Mil. Std. 810C
Thermal conductivity	ASTM C177, C236, C335, C518, C745, D2326
Thermal resistance	ASTM C653, C687

Table B.4. (Continued)

Type of Test	Test Designation
Thermal transference	ASTM C691
Thickness	ASTM C167, C209
Transverse strength	ASTM C209
Vapor permeability	ASTM C355, E96
Weathering, resistance to	ASTM G7

Table B.5. Existing Test Methods for Metals

Type of Test	Test Designation
Acetic acid, resistance to	ASTM B287, B368
Atmospheric pollutants, resistance to	ASTM B537, G33
Compression	ASTM E9, E209
Density and open porosity	ISO 2738
Corrosion, resistance to	ASTM C464, D130, D538, D849, D930, D1280, D1374, D1384, D1616, D1654, D2247, D2251, D2570, D2649, D2809, D2933, D2966, G3, G4, G31, G32, G46, G48, AWPA M-14-72, NACE TM-01-71, TM-02-70, TM-02-74, TM-01-69
Creep	ASTM E139
Creep at elevated temperature	ASTM E150
Ductility	ASTM B489
EMF	ASTM E189
Fatigue	ASTM E466
Fracture toughness	ASTM E399
Grain size	ASTM E112
Hardness	ASTM E10, E18, E103, E110, E384, E448
Impact, resistance to	ASTM E23
Oil content	ISO 2737
Salt spray, resistance to	ASTM B117, G44, Fed. Std. 151b
Stress corrosion	ASTM G30, G35, G37, G38
Tensile strength	ASTM E8
Thermal expansion	ASTM B95, E80

Table B.6. Existing Test Methods for Plastics

Type of Test	Test Designation
Abrasion, mar, resistance to	ASTM D673, D1044, D1242
Atmospheric pollutants, resistance to	ASTM B117, B287, D543, D1149, D1712, G1, G33, Fed. Std. 406
Blister-delamination	ASTM C363
Burst strength	ASTM D774
Cleanability	AIMA-7
Coefficient of expansion	ASTM D696, D864, D1204
Color change	ASTM D1729, D1925, D2244, D2616, D3134, G45, Fed. Std. 141
Creep	ASTM D2552, D2990, D2991, Fed. Std. 406
Deflection	ASTM D621, D648
Density	ASTM D792, D1505
Embrittlement	ASTM D1790
Fatigue	ASTM C394, D671, SAE J783
Flammability	ASTM D635, D658, D876, D1929, D3014, E84, E136
Flatness	ASTM D1604, Fed. Spec. DD-G-1403, Mil. Spec. 3787
Flexural strength	ASTM C393, D747, D790
Fungus resistance	ASTM G21, G22, G29, Fed. Std. 406, Fed. Spec. L-P-380C
Impact strength	ASTM D256, D1790, D1822, D3029, D3099, D3420, ANSI Z97.1, Fed. Std. 406
Indentation-hardness	ASTM D785, D2240, D2583, Fed. Std. 406
Modulus of elasticity	ASTM D638, D695, D882
Moisture, resistance to	ASTM D756, D2126, D2383, Mil. Std. 810C, Fed. Spec. L-P-380C

Table B.6. (Continued)

Type of Test	Test Designation
Optical properties	ASTM E424, E434, Fed. Spec. DD-G-451
Permeability	ASTM C355, D1434, E96, F372, Fed. Std. 406, TAPPI T-482
Refractive index	ASTM D542
Scratches, defects	Fed. Spec. DD-G-1403
Tensile strength	ASTM C297, D638, D882
Thermal aging, resistance to	ASTM D648, D793, D1299, D2115, D2126, D2288, D2445, D2951, D3045, Mil. Std. 810C
Thermal conductivity	ASTM C177, C518
Thickness	ASTM D374, D1777
Ultimate elongation	ASTM D638, D882
Warping, bowing	ASTM D709
Weathering, resistance to	ASTM D1435, D1499, D1501, D2565, G7, G23, G24, G26, Fed. Spec. L-P-508f, Fed. STd. 406, ANSI Z97.1
Wind, resistance to	ASTM E330

Table B.7. Existing Test Methods for Rubber Materials

Type of Test	Test Designation
Adhesion/cohesion	ASTM C719, C766
Adhesion, peel	ASTM C794, D413, D429, D903, D1781, D1876, D2630
Atmospheric pollutants, resistance to	ASTM D518, D1149 (ozone)
Brittleness point	ASTM D2137
Compression-recovery	ASTM F36
Compression set	ASTM D395, D1229
Creep resistance	ASTM D1390, D1456, D1780, D2293, D2294, F38
Extrusion rate	ASTM C603
Flexural strength	ASTM D1184
Flow properties	ASTM C639
Fungus resistance	ASTM D1286, D1877
Impact strength	ASTM D950
Hardness	ASTM C661, D1415, D2240
Low temperature flexibility	ASTM C711, C734, C765, D797, D1053, D1329, D2137
Moisture or liquid immersion, resistance to	ASTM D471, D1101, D1151, D1460, D3137
Sealability	ASTM D1081, F37, F112
Shear strength	ASTM D905, D1002, D2919, D3165
Staining	ASTM D925, D2203
Tear resistance	ASTM D624
Tensile strength	ASTM D412, D897, D906, D2095, D2295, F152
Thermal aging, resistance to	ASTM C771, C792, D573, D865, D1870

Table B.7. (Continued)

Type of Test	Test Designation
Ultimate elongation	ASTM D412
Weathering, resistance to	ASTM C718, C732, C793, D904, D1171, D1183, D1828, D2559, ANSI A116.1, AAMA 802.2, 804.1, 805.2, 806.1, 807.1, 808.1, Fed. Specs. TT-G-410E, TT-S-00227E, TT-S-00230C, TT-S-001543A, TT-S-001657
Young's modulus	ASTM D797

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A study was conducted to obtain information on the performance of materials and components in operational solar industrial process heat (IPH) systems, and to provide recommendations for the development of standards including evaluative test procedures for materials and components. An assessment of the needs for standards for evaluating the long-term performance of materials and components of IPH systems was made. The assessment was based on the availability of existing standards, and information obtained from a field survey of operational systems, the literature, and discussions with individuals in the industry. Field inspections of 10 operational IPH systems were performed. The study did not address the thermal efficiencies and health and safety considerations of IPH systems.

The results of the study are presented in this report. It is concluded that standard test methods are needed for evaluating the long-term performance of materials and components used in IPH systems operating at high temperatures. Some standard test methods are available having applicability to materials and components in low temperature systems. However, in the latter case, data bases are lacking which demonstrate their applicability. Recommendations are made and priorities assigned for the development of standards for materials and components.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Field survey; industrial process heat; materials performance; solar collector; standards; test methods.

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